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SUMMARY

An investigation was conducted in the Langley Spin Tunnel to determine the spin and recovery characteristics of a 1/25-scale model of the General Dynamics F-16XL airplane. Erect and inverted spins at symmetric and asymmetric loadings were tested, and the required emergency spin-recovery parachute size was established. The results of the investigation indicated that an adequate spin-prevention system will eliminate erect spins for the airplane. Without such a system, the airplane will exhibit two flat erect spin modes, one fast and steady, one slower and oscillatory, and a moderately steep, relatively slow inverted spin mode from which acceptable recoveries can be achieved using the recommended control techniques. Lateral mass asymmetries and certain external store loadings were found to degrade the spin and recovery characteristics and to result in poor recoveries.

INTRODUCTION

As part of a cooperative program with General Dynamics, an investigation has been conducted in the Langley Spin Tunnel to determine the spin and spin-recovery characteristics of a 1/25-scale model of the General Dynamics F-16XL airplane. The F-16XL is a derivative of the F-16A with extended range capability designed for the fighter and attack missions. It is a single-place, single-engine airplane with a single vertical tail and a cranked arrow wing incorporating leading- and trailing-edge devices. Previous spin-tunnel tests of the F-16A and a modified version known as the AFTI F-16 are presented in references 1 and 2, respectively.

The investigation consisted of erect and inverted spins and recoveries at symmetric and asymmetric loadings including tests to determine the effects of scaled replica external stores. The sizing requirements for an antispin parachute were examined, and an assessment was made of the ability of the spin-prevention system to preclude the occurrence of the fully developed spin. Brief evaluations of all-moving wing tips, an all-moving vertical tail, vortex flaps, and the proposed spin chute installation are included.

SYMBOLS

b — wing span, ft

$\bar{c}$ — mean aerodynamic chord, ft or in.

C_D — drag coefficient of parachute based on laid-out-flat area, $\dfrac{\text{Drag}}{\frac{1}{2}\rho V^2 S_p}$

d — distance from skirt of uninflated parachute canopy to towline attachment point on airplane, ft

I_X, I_Y, I_Z — moment of inertia about the X, Y, or Z body axis, respectively, slug-ft^2

$\frac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

m mass of airplane, slugs

S wing area, ft^2

S_p parachute area (laid out flat), ft^2

V full-scale true rate of descent, ft/sec

x distance of center of gravity from leading edge of mean aerodynamic chord, ft

z distance between center of gravity and fuselage reference line (positive when center of gravity is below fuselage reference line), ft

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

δ_a aileron deflection, deg; Average = (Left + right)/2

δ_{de} differential elevon deflection, deg

δ_e symmetrical elevon deflection, deg

δ_r rudder deflection, deg

μ relative density of airplane, $m/\rho Sb$

ρ air density, $slugs/ft^3$

ϕ angle between span axis (lateral body axis) and horizontal, deg

Ω full-scale angular velocity about spin axis, deg/sec, sec/turn

Abbreviations:

c.g. center of gravity

IYMP inertia yawing-moment parameter

SS span station

T.E. trailing edge

TER triple ejector rack

MODEL

A 1/25-scale model of the General Dynamics F-16XL airplane was built for testing in the Langley Spin Tunnel. A three-view drawing of the model is shown in figure 1, and photographs of the model are presented in figures 2 through 8. The dimensional characteristics of the full-scale F-16XL airplane are presented in table I. Scaled replicas of various external stores were fabricated of very light materials, and mass effects of these stores were provided by the addition of lead weights. The F-16XL design was undergoing continuing development during the course of this investigation. The configuration changes provided aerodynamic improvements at low angles of attack, but generally were expected to have no effect on the spin and spin-recovery characteristics. Appropriate modifications to the model were made as the configuration developed, and check spins were performed to ensure that the spin and spin-recovery characteristics were unchanged.

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 25 000 ft ($\rho = 0.001065$ slug/ft^3). The mass characteristics, center of gravity, and inertia parameters for the clean airplane and for symmetric loadings of the model as tested are presented in table II. Table III gives a pictorial representation of the loadings.

Because it is impractical to ballast spin-tunnel models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the F-16XL model varied from the true scaled-down values within the following limits:

Weight, percent .... 2.0 low to 2.0 high

Center-of-gravity location, percent $\bar{c}$ .... 0.4 forward to 0.4 rearward

Moments of inertia:
- I_X, percent .... 3.0 low to 3.0 high
- I_Y, percent .... 2.0 low to 3.0 high
- I_Z, percent .... 2.0 low to 2.0 high

A remotely controlled mechanism installed in the model to actuate the controls for recovery attempts provided sufficient torque on the controls to reverse them fully and rapidly for the recovery attempts. The normal maximum control deflections of the airplane used on the model during most of the tests (measured perpendicular to the hinge lines) were

Pitch control:
- Elevons, deg .... 30 up, 30 down
- Leading-edge flaps, deg .... 0, 36.5 down

Roll control:
- Ailerons, deg .... 20 up, 30 down
- Differential elevons, deg .... 30 up, 30 down

Yaw control:
- Rudder, deg .... 30 left, 30 right

SPIN-PREVENTION SYSTEM

The flight control system of the F-16XL incorporates many automatic features to enhance flying qualities. Feedbacks that improve the handling qualities of the airplane at high angles of attack contribute to spin prevention by helping the pilot avoid loss of control. But for the purposes of this investigation, the spin-prevention system was considered to be those features activated by placing the airplane in an imposed initial erect spinning condition; that is, angle of attack approaching 90° and yaw rate in excess of 100° per second. The control-surface configuration commanded by the spin-prevention system under these conditions would be rudder 30° against the yaw rate, average ailerons 25° with the spin, differential elevons ±30° with the spin (commanding left roll in an erect spin to the left), and leading-edge flaps 18.25° down symmetrically, ±18.25° differentially (left flap 36.5° down, right flap 0° in an erect spin to the left). For the airplane, these inputs would occur according to the scheduled thresholds and gains and would reach the stated deflections prior to achieving a fully developed spin. These spin-prevention inputs are not commanded at negative angles of attack.

SPIN-TUNNEL TESTS

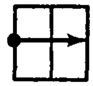
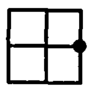
The spin tests of the model were performed in the Langley Spin Tunnel, which is described in reference 3. The test techniques used in spin-tunnel tests are described in detail in reference 3, and a brief summary is given in appendix A of this report. Appendix A discusses the methods and procedures of spin-tunnel testing, including limitations of the facilities and an indication of the interpretation of the quantitative model results to predict full-scale characteristics.

REYNOLDS NUMBER TESTS

Spin-tunnel tests are conducted at Reynolds numbers (on the order of 1.0×10^5) much lower than those encountered by the full-scale airplanes. For some configurations, it has been found that changes in aerodynamic characteristics due to Reynolds number effects can have substantial impact on the spin characteristics (ref. 3). For modern fighter-type designs, the most common source of these Reynolds number effects is the forebody cross flow. Prior to the tests of reference 1, Reynolds number effects on the F-16 at high angles of attack were investigated in the Ames 12-Foot Pressure Wind Tunnel (ref. 4). Based on the results obtained, no modifications to the model were required for the low-Reynolds-number spin-tunnel tests. Since the forebody of the F-16XL is the same as that of the F16 and the F-16A, the results of the Ames tests are considered applicable to this model, and no Reynolds number modifications were made to the model.

RESULTS AND DISCUSSION

The results of the spin tests are presented in tables IV through XII and charts 1 through 5 with model data given in terms of full-scale values for the airplane at an altitude of 25 000 ft. Tests of each control combination are identified by a spin block number corresponding to the control configuration for which the data were obtained. Left and right spins are tested early in the program and a critical direction selected, in this case to the left, but the results are applicable to spins in either direction for the airplane.

The spin block symbol  used in the tables provides a simplified quick reference for indicating the lateral and longitudinal control-surface positions of the model for each test. For the airplane, these control-surface positions are the result of commands from the pilot and the flight control system. In spin-tunnel tests, the flight control laws are not directly modeled, so each spin block shows surface positions which would be commanded for an assumed flight condition. Throughout this report, when, for clarity, descriptions are made in terms of pilot command (e.g., stick forward), the meaning applies to a conventional, unaugmented control system. On the spin block, the top horizontal line represents elevons full trailing edge up (stick back for erect spins, forward for inverted spins), the middle horizontal line elevons neutral, and the bottom horizontal line elevons full trailing edge down (stick forward for erect spins, back for inverted spins). The left vertical line represents ailerons full against the spin (stick left in an erect spin to the pilot's right, stick right in an inverted spin to the pilot's right), the middle vertical line ailerons neutral, and the right vertical line ailerons with, or into, the spin (stick right in an erect spin to the pilot's right, stick left in an inverted spin to the pilot's right). The spin block does not reflect the use of differential elevons for roll control or symmetrical ailerons for pitch control. For example, the spin block  could indicate elevons neutral and ailerons full with or differential elevons full with (average neutral) and ailerons full with. Footnotes to the tables and charts or specific control deflection information is provided to clarify each spin block. The dot represents the control positions for the developed spin, and the arrow indicates the movement of these controls for the recovery attempt. Implementation of the differential leading-edge flap feature was investigated for selected spin conditions, but no significant effect on spin or recovery characteristics was observed, so the symmetric deflection was used for these tests.

Erect Spin and Recovery Tests

Baseline configuration.- Model loading 1, the baseline configuration, represents the F-16XL with 40-percent internal fuel, no external stores, and a c.g. location at $0.460\bar{c}$. The model results for loading 1 are presented in chart 1 and table V.

At the high angle of attack and elevated yaw rate of a spin, the spin-prevention system would command the ailerons and differential elevons full with the spin and rudder against the spin. Spin block 8 of chart 1 represents this configuration except for having rudder with the spin. Even with this prospin rudder contribution, the results show "no spin." That is, the model rate of rotation decreased steadily after launch, and the model entered a glide. Therefore, the spin-prevention system should preclude the development of an equilibrium spin condition. Elimination of the differential elevon command results in the "no spin" condition for full up and full down elevons (spin blocks 7 and 9) as well as for the neutral elevon case. Thus, the antispin aileron command from the spin-prevention system is sufficient to inhibit spins for the baseline configuration.

With lateral control held neutral, prospin rudder may generate one of three conditions at any longitudinal control position (spin blocks 4, 5, and 6). By far, the most frequently observed is a "no spin" condition. The others are two oscillatory modes, a faster one ($\alpha = 70°$ to $85°$ at 3 to 5 seconds per turn) and a slower one ($\alpha = 65°$ to $70°$ at 7 to 8 seconds per turn). Recoveries from the slower mode are excellent, less than 1/2 turn, with aileron and rudder moved full antispin. For

recoveries attempted from the faster mode, 1 1/4 to 2 3/4 turns may be required, but such recoveries are considered good.

When the ailerons are initially set to a prospin deflection, the conditions of spin blocks 1, 2, and 3 are observed. Rather than a clearly identified spin mode with a discrete angle of attack and spin rate, the model exhibits a cyclic behavior. After persisting in a steady, fast, flat spin mode for a number of turns, the spin rate will slowly decrease. Then oscillations in pitch and roll will appear and increase in amplitude. Occasionally the oscillations will increase until the model rolls out of the spin, but usually the oscillations damp out, the yaw rate increases, and the model returns to the steady, fast, flat spin. The process may then repeat itself indefinitely. The values shown on the chart represent the range of values the steady mode may attain - as high as $\alpha = 87°$ at 1.8 seconds per turn to as low as $\alpha = 83°$ at 3.7 seconds per turn. The fluctuations of the transitory phase are too irregular for meaningful measurement. Depending upon entry conditions, the airplane may encounter either phase. An oscillatory entry into the transitory phase will permit rapid recoveries if antispin controls are input before the motions stabilize. Once the fast, flat spin is established, recoveries will be slower. Acceptable recoveries may be achieved from even the fastest spins by reversing the rudder to full against the spin and moving the ailerons and differential elevons to full with the spin. Of these movements, ailerons with the spin is of major importance. Ailerons with the spin combined with differential elevon deflection provided acceptable recoveries from all spins at this loading. As shown in spin blocks 12, 17, 29, and 23, the frequently used recovery technique of rudder reversal with stick full forward and laterally neutral will not effect recovery from developed spins for the F-16XL.

During the configuration development, various changes to the baseline model were evaluated. These variations included all-moving wing tips, an all-moving vertical tail, vortex flaps, and the proposed spin chute installation. A discussion of the results is presented in appendix B.

Forward center-of-gravity location ($0.430\bar{c}$).- Chart 2 presents the results for model loading 6, the most forward c.g. location. The antispin aileron command of the spin-prevention system, ailerons with the spin, is adequate to suppress spins. With neutral ailerons, spin modes are no longer attainable at full positive or negative longitudinal control deflection. For neutral longitudinal control (spin block 36), two conditions are observed, the "no spin" condition and a very slow, oscillatory spin from which excellent recovery is achieved by moving ailerons with the spin. Prospin aileron settings produce a cyclic spinning behavior as seen for the baseline loading, but the range of values observed is narrower, and good recoveries are realized by moving ailerons full with the spin.

Aft center-of-gravity location ($0.491\bar{c}$).- Model loading 7, the most aft center-of-gravity location tested, produced the results summarized in chart 3. For this loading, the prevention of prospin aileron inputs was sufficient to eliminate spins, but with prospin aileron permitted, the cyclic spin behavior exhibited at the other c.g. locations was repeated. Good recoveries of 3 3/4 turns or less were realized by rudder reversal and ailerons with the spin.

External Store Effects

The F-16XL is capable of carrying an unusually large variety and quantity of external stores. Extensive model tests using scaled replicas of several types of

stores were conducted to determine the effects of these stores on the spin and recovery characteristics of the configuration, for both symmetric and asymmetric carriage. Table III illustrates the store loadings tested. Externally mounted stores can affect the spin and recovery characteristics of an airplane through aerodynamic effects and through inertial effects. These effects may be individually adverse, insignificant, or favorable, and in combination may reinforce or counteract one another.

Symmetric store loadings.- Table VI gives the prospin control results for the five different external store loadings tested. The lateral control positions which would be commanded by the spin-prevention feature of the flight control system were sufficient to produce the "no spin" condition, even against full prospin rudder. With the antispin aileron input neutralized ($\delta_a = 0°$), 30° of prospin rudder was insufficient to sustain a spin for any external store loading except loading 5, 10 SUU-65's. For this loading, a slow, oscillatory spin was exhibited from which immediate recovery was achieved with antispin aileron. The five store configurations compared with the no stores loading for the prospin rudder and aileron inputs show essentially the same flat spin with perhaps a tendency for the increased inertias of the stores to sustain spins at the higher values of the range of rotation rates. Acceptable recoveries are achieved from these spins by including the antispin differential elevon with rudder and aileron reversal.

Asymmetric store loadings.- With asymmetric store loadings, the interaction between aerodynamic and inertial effects is most clearly evidenced. For lateral mass asymmetries, a shift in lateral c.g. toward the outboard wing (i.e., spinning into the light wing) is detrimental to erect spin and recovery characteristics, and a shift toward the inboard wing is beneficial.

In table VII the aerodynamic effects (no mass asymmetry) of asymmetric stores on F-16XL erect spins are shown for inboard and outboard wing-tip locations, and inboard and outboard wing pylon installations. For prospin control deflections, the addition of a 370-gallon tank shape to the inboard wing severely degraded the spin, increased the angle of attack, and substantially increased the rate of rotation to 1.6 seconds per turn. Unsatisfactory recoveries of over 5 turns were observed. The same tank shape moved to the outboard wing, however, produced results within the normal range of the baseline configuration. For the wing-tip-mounted AMRAAM missile shapes, a launcher rail was installed on the model wing tips. The launcher rail remained on the wing tip when the AMRAAM was removed. The AMRAAM shape on the inboard wing tip showed little effect on the spin, except, perhaps, for a slight increase in rotation rate. Recoveries were similar to those of the baseline loading. Switching the AMRAAM shape to the outer wing tip produced a "no spin" condition.

Actual asymmetric store loadings would, of course, entail mass asymmetries. The antispin control positions which would be commanded by the spin-prevention system were sufficient to inhibit developed spins for all asymmetric loadings tested. Table VIII presents the results for prospin control settings for asymmetric external store loadings including the appropriate mass effects.

For the AMRAAM missile loadings, the mass effect dominates. All inner-wing-heavy loadings showed very good recoveries of less than 2 turns. For asymmetries of 3010 and 4860 ft-lb, the outer-wing-heavy loadings produced spins and recoveries similar to the symmetric loading. At an asymmetry of 7830 ft-lb, the increased rotation rates resulted in unsatisfactory recoveries of up to 7 turns. The pylon-mounted AGM-65's exhibited detrimental aerodynamic effects in addition to the mass effects. For the same magnitude of mass asymmetry (4860 ft-lb), which showed little effect

with a wing-tip AMRAAM (spin block 75), the pylon-mounted AGM-65's gave faster spins and poorer recoveries (spin blocks 95 and 97). Loading 5 (10 SUU-65's), the worst symmetrical loading (spin block 105), showed the fastest spins and slowest recoveries. The asymmetry produced by removing the outermost store resulted in expectedly poor recoveries of 7 and 8 turns (spin block 106).

In spin block 109, asymmetric TER-mounted AGM-65's showed better recoveries than the pylon-mounted configurations even though the mass asymmetry was nearly twice as large. The largest mass asymmetry tested for actual store loadings was 18 300 ft-lb for one full 370-gallon drop tank (loading 8a). Spin block 107 showed that with this outer-wing-heavy asymmetry, the spin would be extremely rapid at 1.4 seconds per turn and virtually unrecoverable. Of the loadings tested, the asymmetric tank was the only one for which both antispin ailerons and differential elevons were required to inhibit a developed spin. With elevons full trailing edge down, full antispin ailerons, and rudder with the spin, a spin at $\alpha = 79°$ and 3 seconds per turn could be sustained (spin block 108). A slow recovery from this spin could be obtained by rudder reversal and differential elevon with the spin.

Inverted Spin and Recovery Tests

The spin-prevention feature of the flight control system does not function at negative angles of attack, so the inverted spin tests are interpreted in terms of a conventional control system with full pilot authority to maintain prospin controls. External stores mounted under the wing would be completely shielded in the inverted spin, so no tests of aerodynamic effects of such stores were conducted. The effects of lateral mass asymmetry were investigated. The inverted spin tests were conducted with 0° leading-edge-flap deflection. After the flight control system was modified to incorporate a deflection of 6.4° up for negative angles of attack, selected spins were repeated with these settings, but no significant differences were observed in the spin or recovery characteristics.

Baseline configuration.- The results for model loading 1, the baseline configuration, representing the F-16XL with 40-percent internal fuel, no external stores, and a c.g. location at $0.460\bar{c}$, are presented in chart 4. Most control settings sustain relatively slow (5 to 8 seconds per turn) inverted spins with roll oscillations up to ±30° and pitch oscillations varying from $\alpha = -50°$ to $-80°$. The smoothest spins (average $\alpha = -65°$ at 5 to 6 seconds per turn) are seen with neutral lateral controls, spin blocks 48, 49, and 50. The fastest spin, 4.2 seconds per turn, is generated by ailerons full against the spin, rudder full with, and longitudinal control neutral (block 46). Good recoveries of 1 1/2 turns or less are realized by neutralizing all controls.

Asymmetric loadings.- Table IX presents the model results for inverted spins with a mass asymmetry equivalent to 5000 ft-lb, full-scale, imposed on the baseline configuration. The control setting used was ailerons against, longitudinal controls neutral, and rudder with, because this setting produced the fastest inverted spins with symmetric loadings. Recoveries were attempted by neutralizing ailerons and either neutralizing or reversing the rudder.

When the mass asymmetry was outer wing heavy (right wing heavy for a spin to the pilot's left), 15° of rudder deflection would not sustain a spin. Increasing the prospin rudder to 30° produced two possible conditions, a "no spin" and an oscillatory, fairly rapid mode from which good recoveries were achieved by neutralizing all controls. Placing the mass asymmetry on the inside wing enabled a sustained spin

mode, with a rudder deflection of 15°. This mode was relatively smooth at an angle of attack of -66° and fairly slow at 5.3 seconds per turn. Neutralization of all controls had little noticeable effect, and the model continued to spin. Increasing the prospin rudder deflection to 30° generated a more oscillatory spin in pitch and roll, which also did not recover by neutralization of controls. Reversing the rudder, however, to 30° antispin gave excellent 1/4- to 1/2-turn recoveries.

Inverted spins for the symmetrically loaded airplane will be relatively smooth with an average angle of attack near -65° and a turn rate of 4 to 6 seconds per turn, or oscillatory with angle of attack varying within the range from -50° to -80° and a turn rate of 5 to 8 seconds per turn. Good recoveries of 1 1/2 turns or less may be realized by neutralizing all controls. For asymmetric loadings of up to 5000 ft-lb, such that the airplane is spinning into the heavy wing, full rudder reversal will be required with neutralization of other controls.

Spin-Recovery Parachute Tests

The results of model tests of spin-recovery parachutes are presented in tables X, XI, and XII. These tests are conducted to establish the parachute size and towline length necessary to provide emergency spin recovery. Therefore, for erect spins, severely degraded control-system conditions are tested and extreme lateral mass asymmetries imposed to ensure parachute effectiveness under the most adverse circumstances. The towline length represents the distance from the lower lateral band or skirt of the parachute canopy to the attachment point on the airplane (riser length + shroudline length).

Symmetric loadings.- In table X, the effects of parachute size and towline length on recoveries with prospin controls maintained are shown. For the smallest parachute tested, 28.2-ft-diameter full-scale, the 75-ft towline provided acceptable 3- to 4 3/4-turn recoveries, but considerable interaction with the model wake was observed. Slightly better recoveries occurred with the 100-ft towline; however, longer towlines of 125 and 150 ft produced a noticeable degradation in recoveries. On 100-ft towlines, a 31.5-ft-diameter parachute showed excellent recoveries at less than 2 turns, and a 34.2-ft chute gave good recoveries of less than 3 turns. Increasing the towline to 150 ft also degraded recovery. The largest parachute tested, 39.1 ft full-scale, on the 100-ft towline showed no improvement over the 34.2-ft chute.

Asymmetric loadings.- In table XI, the effect of lateral mass asymmetry without store shapes on spin chute effectiveness is presented. Based on the results discussed above, only the 100-ft towline length was evaluated for three parachutes. The 28.2-ft-diameter parachute generally showed marginally unsatisfactory recoveries with occasional unacceptable recoveries at 5000-ft-lb asymmetry. At larger asymmetries, very poor recoveries were consistently observed. Good 2 1/4- to 2 3/4-turn recoveries were produced by the 34.2-ft-diameter parachute with no asymmetry, but recoveries became marginally unsatisfactory for 5000 ft-lb. Asymmetries of 10 000 ft-lb and greater were consistently poor. A 39.1-ft parachute did not evidence any clear improvement over the 34.2-ft size.

Simultaneous control movement.- When antispin parachute sizes become excessive, relief is sometimes provided by incorporating automatic control-system features to ensure proper control movement in conjunction with parachute deployment. In table XII, the improvements possible in the recovery performance of the 34.2-ft-diameter parachute using control movements are shown. Neutralizing rudder and

aileron is not sufficient at 5000-ft-lb asymmetry, but full reversal of these controls, however, did produce consistently acceptable recoveries with asymmetries up to 10 000 ft-lb. At 15 000 ft-lb, even rudder and aileron reversal did not give acceptable recoveries.

For the F-16XL, a 34.2-ft-diameter parachute with a drag coefficient of 0.50 on a 100-ft towline deployed in conjunction with the reversal of rudder and ailerons will produce satisfactory emergency spin recovery for the airplane with lateral mass asymmetries up to 10 000 ft-lb. Appendix C presents a study justifying the use of a smaller diameter spin chute for one specific, limited flight-test condition.

CONCLUDING REMARKS

Based on results of spin-tunnel tests of a 1/25-scale model of the F-16XL airplane and other available information on spinning characteristics of fighter-type airplanes, the following conclusions regarding the spin and recovery characteristics of the airplane at an altitude of 25 000 ft are drawn:

1. The spin-prevention feature of the flight control system will inhibit fully developed erect spins for the basic airplane and for the airplane with symmetric and asymmetric external store loadings with lateral mass asymmetries up to 18 000 ft-lb.

2. With no spin-prevention system functioning, two erect spin modes may be observed, a fast, flat spin at an angle of attack of approximately 85° and 2 to 3 seconds per turn and a flat oscillatory mode with an angle of attack varying from 65° to 85° and turn rates from 3 to 8 seconds per turn.

3. For the basic airplane and most symmetric external store loadings, satisfactory recoveries from the erect spin may be obtained by simultaneously and briskly moving the ailerons and differential elevons full with the spin and the rudder full against the spin. It should be emphasized that control movements for recovery must be rapid. Flight-test experience has shown that slower movement of the control surfaces to the recovery position, whether by pilot or automatic system, may not effect spin recovery.

4. Lateral mass asymmetries (outer wing heavy) degrade the erect spin and recovery characteristics of the airplane. The recommended recovery technique of briskly moving the ailerons and differential elevons full with the spin and rudder full against the spin will produce slow recoveries for certain store loadings with asymmetries up to 3000 ft-lb and may not generate satisfactory recoveries at larger asymmetries.

5. For the basic airplane and the airplane with symmetrical loadings, the inverted spin will be smooth with an angle of attack near -65° at 4 to 6 seconds per turn, or oscillatory, with an angle of attack from -50° to -80° and 5 to 8 seconds per turn. Good recoveries will be achieved by neutralizing all controls.

6. For asymmetric loadings of up to 5000 ft-lb such that the inside wing is heavy, full rudder reversal along with neutralization of lateral controls will produce excellent recoveries from the inverted spin.

7. A 34.2-ft-diameter parachute with a drag coefficient of 0.50 and a 100-ft towline deployed in conjunction with the movement of ailerons and rudder to full antispin deflection will enable emergency recovery from all spins for the airplane with lateral mass asymmetries up to 10 000 ft-lb.

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APPENDIX A

TEST METHODS AND PRECISION

Model Testing Technique

Detailed discussions of spin-model testing techniques, methods of interpreting test results, and correlation between model and airplane results are presented in reference 3. Spin-tunnel tests are usually performed to predict the spin and recovery characteristics which might be encountered by a full-scale airplane at altitude during planned flight testing or through inadvertent loss of control. This prediction is made based upon the results of extensive free-spinning tests of dynamically scaled models in the spin tunnel interpreted in the light of correlations obtained between model tests and flight tests for similar configurations. Model test parameters encompass the full range of airplane loading conditions such as weight, center of gravity, and inertia yawing-moment parameter. Configuration variables such as external stores, flaps, speed brakes, refueling probes, and parachute installations are investigated. Throughout, a full matrix of control deflections, singly and in combination, including neutral and maximum settings of the control surfaces are evaluated.

The controls are preset to the desired prospin deflections, and the model is hand launched into the vertically rising airstream. A radio signal releases a mechanism in the model and permits the spring-loaded controls to move abruptly to the predetermined recovery position. Recovery is typically attempted first by moving rudder(s) and ailerons from prospin to antispin. Control neutralization and rudder reversal alone may be assessed. Use of longitudinal control movement for recovery can also be incorporated as required. The critical prospin and optimum recovery control deflections are determined by both the aerodynamic and mass distribution characteristics of the model.

Modern fighter aircraft are generally designed with a relatively long fuselage forebody, which has an added aerodynamic influence on the spin, and a vertical stabilizing surface (or surfaces), which are usually shielded from effective airflow at high angles of attack. The mass characteristics are such that the fuselage is heavily loaded relative to the wings, and the relative density μ is considerably higher than that of airplanes referred to in reference 3. The overall effect of these design characteristics is to cause the roll control surfaces (ailerons and/or differential tail) rather than the rudder to become the primary recovery control.

When investigations are made of modifications to a previously tested model, a greatly reduced matrix of test conditions may be employed. Depending upon the nature of the modifications, only selected critical spins, loadings, and recovery procedures need be assessed.

Data acquisition is from high-speed color motion pictures of the tests. Angles of attack and bank are read from the film with a precision optical reader. Tunnel speed is superimposed on the film and is used to calculate the full-scale velocity. A time code is also superimposed on the film to permit the determination of angular velocity.

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases. Satisfactory recovery characteristics are established by several factors rather than by a predetermined number of turns. In reference 3,

a 2 1/4-turn criterion is mentioned. This was based on the experience gained for many model test programs up to that time. Subsequently, the design characteristics of fighter aircraft in particular have changed significantly. For a modern fighter aircraft exhibiting a fast, flat spin, a 4-turn recovery might be termed satisfactory after consideration of altitude loss per turn, consistency of recovery, complexity of control manipulation, and sensitivity to deviations from optimum procedure. For recovery attempts in which a model strikes the safety net while it is still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, for example, >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. A recovery in 10 or more turns is often indicated by ∞. When a model loses the rotation applied at launch within a few turns and recovers without control movement (rudder and other controls held with the spin), the results are recorded as "no spin."

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net, for example, >300 ft/sec full-scale. In such tests, the recoveries are attempted before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude.

For spin-recovery parachute tests, the parachute system required to effect satisfactory recovery is determined. The parachute is deployed for the recovery attempts by actuating a remote control mechanism, and the controls are maintained prospin so that recovery is effected by the parachute action alone.

Accuracy

Results determined in free-spinning tunnel tests are estimated to be correct values within the following limits:

α, deg	±1
ϕ, deg	±1
V, percent	±2
Ω, percent	±2
Turns for recovery obtained from motion-picture records	±1/4
Turns for recovery obtained visually during tests	±1/2

All data presented are from motion-picture records unless stated as being from visual observation of a video-tape recording. The preceding limits may be exceeded for certain spins in which the model is difficult to control in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

APPENDIX B

ADDITIONAL CONFIGURATION STUDIES

Several unconventional features were evaluated during the configuration development of this airplane for flying qualities and performance improvement. Although generally not designed specifically for the spinning condition, certain of these features were tested for selected critical spins on the spin-tunnel model to determine the effects on spin and spin-recovery characteristics.

All-Moving Vertical Tail

The dimensions of the all-moving vertical tail for this airplane are given in table I, and figure 8 shows a photograph of the model equipped with this vertical tail. The wing planform of this configuration, combined with the very flat spin modes, produces a large wake which effectively shields the vertical tail. Model tests showed no detectable differences in the spin or spin-recovery characteristics of this configuration for the all-moving vertical tail compared with the conventional vertical tail.

All-Moving Wing Tips

Figure 8 shows a photograph of the model with all-moving wing tips for lateral control. Chart 5 gives the model results for this configuration which was tested with the all-moving vertical tail. The same general spin characteristics were observed as have been described previously. At neutral lateral controls, only the "no spin" condition was observed, and for spins with prospin lateral control, the varying rate spins noted before were evident. Recoveries from the steady conditions were in the same range as the basic airplane but were more consistent and slightly better. Differential elevon deflection was not required for satisfactory recovery.

Vortex Flap

The vortex-flap configuration shown in figure 9 was tested on the model. No significant effects were observed on the spin or spin-recovery characteristics.

Spin Chute System

Figure 10 shows a photograph of a scaled replica of the spin chute canister and related structure installed on the model. Tests were conducted to determine whether the installation of this system would affect the spin or recovery characteristics of the airplane. No significant effects of this installation were observed during these tests.

APPENDIX C

SMALLER ANTISPIN PARACHUTE FOR LIMITED ENVELOPE FLIGHT TESTS

As noted in the text of this report, emergency spin-recovery parachute sizing normally encompasses a wide range of possible flight conditions and results in rather large parachute requirements. Implementation of such parachute systems often imposes severe penalties on the test vehicle. To alleviate these penalties, certain compromises in the sizing procedure can be made; however, the margin for error is correspondingly reduced. The first compromise, use of recovery controls in conjunction with the spin chute, has already been discussed in the text. This precludes any allowance for the possibility of pilot disorientation or incapacitation or control system malfunction, which might prevent the application of recovery controls.

A second compromise is to strictly limit the maximum asymmetric store loading which will be permitted on the test airplane. For the F-16XL, the asymmetric store configuration selected was model loading 2c, a wing-tip-mounted AMRAAM and a pylon-mounted AMRAAM on the same side of the airplane. This arrangement entails a lateral mass asymmetry of approximately 7830 ft-lb. The critical spin for this loading would be outer wing heavy; i.e., both missiles on the left wing in a spin to the pilot's right. As shown by spin block 73 in table VII, the wing-tip missile has a favorable aerodynamic influence in this case. With mass effects included, spin block 88 in table VIII shows unsatisfactory recoveries of up to 7 turns. Tests of recoveries for this loading using a 28.2-ft-diameter parachute on a 100-ft towline (full-scale values) in conjunction with the recommended recovery control movements gave the following results:

Turns for recovery: 3, 3 1/2, 3, 3, 3, 3 3/4

These results indicate that deployment of the 28.2-ft-diameter parachute on a 100-ft towline, in conjunction with the brisk movement of ailerons and differential elevons full with the spin and rudder full against the spin, will provide emergency spin recovery for a lateral mass asymmetry of up to 7830 ft-lb with AMRAAM missiles on the wing tip and pylon. The 28.2-ft parachute may not be adequate for a similar mass asymmetry produced by other asymmetric store loadings or fuel imbalance.

REFERENCES

1. Scher, Stanley H.: Spin-Tunnel Investigation of a 1/25-Scale Model of the General Dynamics F-16A Airplane - COORD NO. AF-AM-507. NASA TM SX-80149, U.S. Air Force Systems Command, 1979.

2. Scher, Stanley H.; and White, William L.: Spin-Tunnel Investigation of a 1/25-Scale Model of the General Dynamics AFTI F-16 Airplane. NASA TM SX-83243, U.S. Air Force Systems Command, 1982.

3. Neihouse, Anshal I.; Klinar, Walter J.; and Scher, Stanley H.: Status of Spin Research for Recent Airplane Designs. NASA TR R-57, 1960. (Supersedes NACA RM L57F12.)

4. Keener, Earl R.; and Howell, Michael H.: Static Aerodynamic Characteristics of a 1/9-Scale Model of the F-16 Airplane at Angles of Attack of $\pm 90°$ and Angles of Sideslip of $\pm 30°$ at a Mach Number of 0.20. NASA TM-78435, 1978.

TABLE I.- DIMENSIONAL CHARACTERISTICS OF GENERAL DYNAMICS F-16XL AIRPLANE

Overall length, ft	54.2
Wing:	
Span, ft	32.4
Area, ft^2	646.37
Mean aerodynamic chord, in.	296.4
Aspect ratio	1.624
Taper ratio	0.117
Leading-edge sweep (inboard/outboard), deg	70/50
Incidence, deg	-0.65 at root
Twist, deg	-4.104 at SS 136.1 and tip
Dihedral, deg	0
Airfoil	NACA 64A (SS 41.5 to SS 136.1) Modified biconvex (SS 136.1 to tip)
Elevon area (total), ft^2	36.47
Aileron area (total), ft^2	25.66
Leading-edge flap area (total), ft^2	18.71
Vertical tail:	
Area, ft^2	54.75
Leading-edge sweep, deg	47.5
Span, in.	101.0
Aspect ratio	1.294
Taper ratio	0.437
Airfoil section:	
Root chord	5.3-percent biconvex
Tip chord	3.0-percent biconvex
Rudder area, ft^2	11.65
All-moving vertical tail (excluding dorsal pod):	
Area, ft^2	24.5
Leading-edge sweep, deg	37
Span, in.	67.7
Aspect ratio	1.299
Taper ratio	0.300
Airfoil section:	
Root chord	6.0-percent biconvex
Tip chord	3.5-percent biconvex

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR AIRPLANE AND MODEL LOADINGS

[Values given are full scale, and moments of inertia are given about the c.g.]

Loading no.	Description	Weight, lb	Center-of-gravity location		Relative density, μ, at -		Moments of inertia, slug-ft^2			Mass parameters $\times 10^4$		
			$x/\bar{c}$	$z/\bar{c}$	Sea level	25 000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane												
1	Clean configuration (baseline)	24 800	0.460	0.000	15.5	34.7	9 400	67 900	74 800	-723	-85	809
Model												
1	Clean configuration (baseline)	24 547	0.460	0.008	15.3	34.4	9 112	68 427	74 405	-741	-75	815
2	AMRAAM's	26 372	0.487	0.009	16.4	36.9	19 666	73 811	89 064	-630	-177	807
3	AGM-65's (singly mounted)	28 402	0.464	0.008	17.7	39.8	18 709	72 000	87 020	-576	-162	738
4	AGM-65's (on TER racks)	28 198	0.462	0.006	17.6	39.5	15 961	70 056	81 817	-588	-128	716
5	SUU-65's	35 255	0.485	0.001	22.0	49.4	24 577	84 284	103 361	-519	-166	685
6	Forward c.g. (clean)	24 577	0.430	0.008	15.3	34.4	9 584	67 163	72 818	-719	-71	789
7	Aft c.g. (clean)	24 577	0.491	0.008	15.3	34.4	9 564	66 718	72 539	-713	-73	786
8	Two 370-gallon tanks	30 253	0.473	0.004	18.9	42.4	16 220	70 210	84 650	-547	-146	694

TABLE III.- EXTERNAL STORE LOADINGS

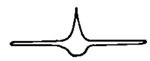
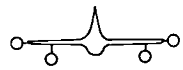
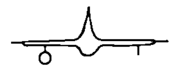
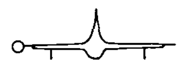
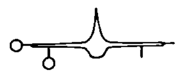
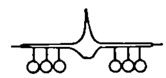
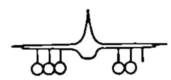
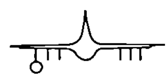
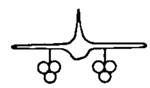
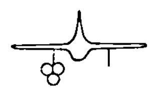
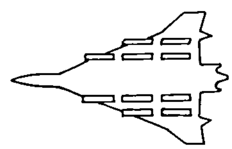
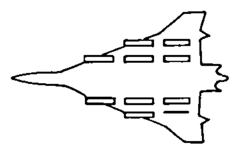
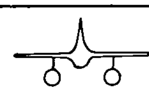
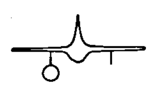
Loading no.	Description	Wing-tip launcher rails	Symmetry	Pictorial representation (not to scale)
1	Clean airplane (baseline; no external stores)	Off	Symmetric	
2	Four AMRAAM missiles (two wing-tip mounted, two pylon mounted)	On	Symmetric	
2a	One AMRAAM missile (pylon mounted)	On	Asymmetric	
2b	One AMRAAM missile (wing-tip mounted)	On	Asymmetric	
2c	Two AMRAAM missiles (one wing-tip mounted, one pylon mounted)	On	Asymmetric	
3	Six AGM-65 missiles (on six single pylons)	On	Symmetric	
3a	Five AGM-65 missiles (on five single pylons)	On	Asymmetric	
3b	One AGM-65 missile (on outboard pylon)	On	Asymmetric	
4	Six AGM-65 missiles (on TER racks)	On	Symmetric	
4a	Three AGM-65 missiles (on one TER rack)	On	Asymmetric	
5	Ten SUU-65 stores (on 10 pylons)	On	Symmetric	
5a	Nine SUU-65 stores (outboard rear pylon empty)	On	Asymmetric	
8	Two 370-gallon drop tanks	On	Symmetric	
8a	One 370-gallon drop tank	On	Asymmetric	

TABLE IV.- FOOTNOTES TO TABLES AND CHARTS OF SPIN AND RECOVERY CHARACTERISTICS

a. On separate tests, a flat, fast, steady spin could be obtained anywhere within the ranges noted. The model may also begin to precess and enter a transitory, oscillatory phase for a few turns and then roll out, or the oscillations may damp and the model return to the flat, fast spin mode. This cycle is repetitive.

b. Recovery attempted from the transitory phase.

c. Differential leading-edge flaps used for recovery attempts simultaneously with other controls as noted. The leading-edge flap on the inner (left) wing remained full down, and the outer (right) wing leading-edge flap was moved to neutral.

d. Differential leading-edge flaps used for recovery attempts simultaneously with other controls noted. The leading-edge flap on the outer (right) wing remained full down, and the leading-edge flap on the inner (left) wing was moved to neutral.

e. Two conditions possible.

f. As the applied rotation damped, the model slowed and entered a glide.

g. As the applied rotation damped, the model slowed and entered an inverted glide.

h. From video tape.

i. Recovery attempted by moving the elevon differentially (±30°) with the spin (stick left in a left spin) simultaneously with the other controls as noted.

j. Model launched with antispin differential elevon and aileron deflection.

k. Oscillatory spin. Range or average of values given.

ℓ. Three conditions obtained.

m. Recovery attempted by simultaneous movement of the rudder to full against the spin and the ailerons to full with the spin (stick left in a left spin).

n. Recovery attempted by simultaneous movement of the rudder to full against the spin and the ailerons and elevons to neutral.

o. Recovery attempted by simultaneous movement of rudder and roll control to neutral, elevons as shown.

p. After recovery, the model rolled into an erect glide.

q. After recovery, the model entered an inverted glide.

r. After recovery, the model made a half loop into an erect glide.

s. Recovery attempted by simultaneous movement of all controls to neutral.

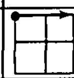
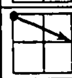
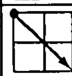
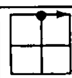
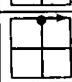
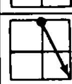
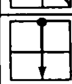
t. Dishing, a wandering motion of the model due to precession of the spin axis.

u. Both elevons down 30° and both ailerons down 30° for the steady spin.

TABLE V.- ERECT SPIN AND RECOVERY CHARACTERISTICS FOR THE BASELINE CONFIGURATION USING VARIOUS CONTROL TECHNIQUES

[Model loading 1; leading-edge flaps 36.5° down]

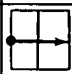
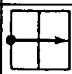
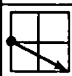
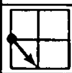
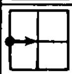
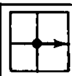
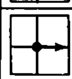
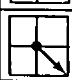
TEU - trailing edge up W - with U - inner wing up
TED - trailing edge down A - against D - inner wing down

Spin block no.	Spin block	Spin characteristics: α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
1		[a]87-83	1U	250-270	190-100 (1.9-3.7)	30W / 30A	30TEU / 30TEU	25A / 25W	0 / 0	3, [b]2, $4\frac{3}{4}$, $5\frac{3}{4}$, $3\frac{1}{2}$, 3
10		[a]87-83	1U	250-270	190-100 (1.9-3.7)	30W / 30A	30TEU / 0	25A / 25W	0 / 0	[b]$2\frac{1}{4}$, $2\frac{3}{4}$, $4\frac{1}{2}$, [b]2, [b]$2\frac{1}{4}$
11		[a]87-83	1U	250-270	190-100 (1.9-3.7)	30W / 30A	30TEU / 30TED	25A / 25W	0 / 0	3, $2\frac{1}{4}$, $3\frac{1}{4}$, [b]$1\frac{3}{4}$, $4\frac{1}{2}$
13		[a]87-83	1U	250-270	190-100 (1.9-3.7)	30W / 0	30TEU / 0	25A / 0	0 / 0	9
12		[a]87-83	1U	250-270	190-100 (1.9-3.7)	30W / 30A	30TEU / 30TED	25A / 0	0 / 0	∞, $8\frac{1}{2}$
ℓ, f_4		[k]80 72	3U 9D	260	85 (4.3)	30W / 30A	30TEU / 30TEU	0 / 25W	0 / 0	$2\frac{1}{4}$, $1\frac{1}{2}$
ℓ, f_4		[k]80 70	6U 9D	300	55 (6.7)	30W / 30A	30TEU / 30TEU	0 / 25W	0 / 0	$\frac{1}{8}$, $\frac{1}{8}$
27		[k]80 70	6U 9D	300	55 (6.7)	30W / 30A	30TEU / 0	0 / 25W	0 / 0	$\frac{1}{8}$, $\frac{1}{8}$
28		[k]80 70	6U 9D	300	55 (6.7)	30W / 30A	30TEU / 30TED	0 / 25W	0 / 0	$\frac{1}{8}$, $\frac{1}{8}$
29		[k]80 70	6U 9D	300	55 (6.7)	30W / 30A	30TEU / 30TED	0 / 0	0 / 0	∞

See footnotes in table IV.

TABLE V.- Continued

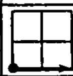
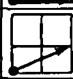
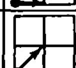
TEU - trailing edge up W - with U - inner wing up
TED - trailing edge down A - against D - inner wing down

Spin block no.	Spin block	Spin characteristics: α, deg	φ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
2		[a]87-83	2U 1D	240-270	200-110 (1.8-3.3)	30W / 30A	0 / 0	25A / 25W	0 / 0	5, $4\frac{1}{2}$, $7\frac{3}{4}$, 4, $6\frac{1}{2}$, [b]$1\frac{3}{4}$, [b]$2\frac{1}{2}$, 3, 4, 5, $5\frac{1}{4}$, 6
14		[a]87-83	2U 1D	240-270	200-110 (1.8-3.3)	30W / 30A	0 / 0	25A / 25W	0 / 30W	[i]$4\frac{1}{2}$, $4\frac{1}{2}$, $3\frac{1}{2}$
15		[a]87-33	2U 1D	240-270	200-110 (1.8-3.3)	30W / 30A	0 / 30TED	25A / 25W	0 / 0	$4\frac{3}{4}$, $5\frac{3}{4}$, $4\frac{3}{4}$, 3, $5\frac{1}{2}$, [b]$2\frac{1}{2}$, $5\frac{1}{2}$
17		[a]87-33	2U 1D	240-270	200-110 (1.8-3.3)	30W / 0	0 / 30TED	25A / 0	0 / 0	6, 8, ∞, ∞
19		[a]87-33	2U 1D	240-270	200-110 (1.8-3.3)	30W / 30A	0 / 0	25A / 0	0 / 0	$8\frac{1}{2}$, $9\frac{1}{2}$, $11\frac{1}{2}$, $8\frac{1}{2}$, $8\frac{1}{4}$
ℓ,f5		[k]85 72	4U 3D	250	120 (3.0)	30W / 30A	0 / 0	0 / 25W	0 / 0	2, $2\frac{3}{4}$
ℓ,f5		[k]72 64	6U 8D	280	45 (8.0)	30W / 30A	0 / 0	0 / 25W	0 / 0	$\frac{1}{8}$, $\frac{1}{4}$
25		[k]72 64	6U 8D	280	45 (8.0)	30W / 30A	0 / 30TED	0 / 25W	0 / 0	$\frac{1}{8}$, $\frac{1}{8}$

See footnotes in table IV.

TABLE V.- Concluded

TEU - trailing edge up   W - with   U - inner wing up
TED - trailing edge down   A - against   D - inner wing down

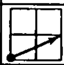
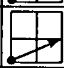
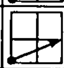
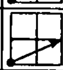
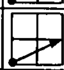
Spin block no.	Spin block	Spin characteristics				Control deflection, deg (For spin / For recovery)				Turns for recovery
		α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	δ_r	δ_e	δ_a	δ_{de}	
3		[a]86-83	2U 2D	245-265	165-130 (2.2-2.7)	30W / 30A	30TED / 30TED	25A / 25W	0 / 0	[b]$2\frac{1}{2}$, $3\frac{3}{4}$, $3\frac{1}{2}$, $3\frac{3}{4}$, $4\frac{1}{2}$, $3\frac{1}{4}$, $4\frac{1}{2}$, 5, 6
21		[a]86-83	2U 2D	245-265	165-130 (2.2-2.7)	30W / 30A	30TED / 0	25A / 25W	0 / 0	3, $4\frac{1}{2}$, [b]$2\frac{1}{4}$, $2\frac{3}{4}$, 6, $5\frac{3}{4}$
22		[a]86-83	2U 2D	245-265	165-130 (2.2-2.7)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	4, $3\frac{1}{4}$, 4, $2\frac{3}{4}$, 2, 3, [b]$1\frac{1}{2}$, [b]$1\frac{3}{4}$
23		[a]86-83	2U 2D	245-265	165-130 (2.2-2.7)	30W / 30A	30TED / 30TED	25A / 0	0 / 0	7, $10\frac{3}{4}$, 10, 11, 8, ∞, [c]$6\frac{1}{4}$, [c]6, [d]9
26		[a]86-83	2U 2D	245-265	165-130 (2.2-2.7)	30W / 30A	30TED / 0	25A / 0	0 / 0	∞, ∞

See footnotes in table IV.

TABLE VI.- EFFECT OF SYMMETRIC STORE LOADINGS

[Leading-edge flaps 36.5° down]

TEU - trailing edge up W - with U - inner wing up
TED - trailing edge down A - against D - inner wing down

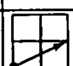
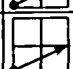
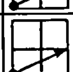
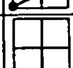
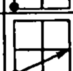
Spin block no.	Spin block	Stores: Loading	Stores: Description	Spin characteristics: α, deg	Spin characteristics: ϕ, deg	Spin characteristics: V, ft/sec	Spin characteristics: Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
22		1	None	[a]86-83	1U	245-265	165-135 (2.2-2.7)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	4, $3\frac{1}{4}$, 4, $2\frac{3}{4}$, 2, 3, [b]$1\frac{1}{2}$, [b]$1\frac{3}{4}$
121		8	Two 370-gallon drop tanks	[a]86-84	1U	250	180-165 (2.0-2.2)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, 3
70		2	Four AMRAAM missiles	[a]87-83	0 3U	240-260	190-145 (1.9-2.5)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{2}$, $2\frac{3}{4}$, $4\frac{1}{2}$, $3\frac{1}{2}$
102		4	Six AGM-65 missiles (TER's)	86	1U	240	180 (2.0)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, $3\frac{1}{2}$
11		3	Six AGM-65 missiles (pylons)	86	1D	240	165 (2.2)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, $3\frac{1}{4}$
105		5	Ten SUU-65 stores	88	7U 10D	290	225 (1.6)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	5, $4\frac{3}{4}$, 5

See footnotes in table IV.

TABLE VII.- AERODYNAMIC EFFECTS OF ASYMMETRIC STORE LOADINGS

[Leading-edge flaps 36.5° down]

TEU - trailing edge up W - with U - inner wing up
TED - trailing edge down A - against D - inner wing down

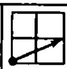
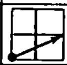
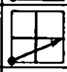
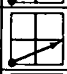
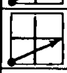
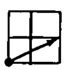
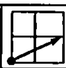
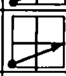
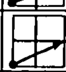
Spin block no.	Spin block	Stores: Loading	Stores: Description	Spin characteristics: α, deg	Spin characteristics: ϕ, deg	Spin characteristics: V, ft/sec	Spin characteristics: Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
22		1	None	[a]86-83	1U	245-265	165-135 (2.2-2.7)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	4, $3\frac{1}{4}$, 4, $2\frac{3}{4}$, 2, 3, [b]$1\frac{1}{2}$, [b]$1\frac{3}{4}$
125		8a	One 370-gallon tank (inner wing)	88	1U	240	225 (1.6)	30W / 30A	30TEU / 0	25A / 25W	0 / 30W	$5\frac{1}{2}$, [h]$5\frac{1}{4}$
111		8a	One 370-gallon tank (outer wing)	84	5U 3D	240	150 (2.4)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	[b]$1\frac{3}{4}$, 4
73		2b	One AMRAAM (outer wing tip)	No spin				30W	30TED	25A	0	No spin
77		2b	One AMRAAM (inner wing tip)	86	3D	235	180 (2.0)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$3\frac{1}{2}$, 2, $2\frac{1}{2}$, 4

See footnotes in table IV.

TABLE VIII.- EFFECT OF ASYMMETRIC STORE LOADINGS (AERODYNAMIC AND INERTIAL EFFECTS)

[Leading-edge flaps 36.5° down]

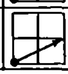
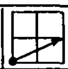
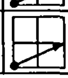
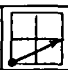
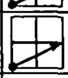
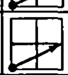
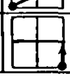
TEU - trailing edge up W - with U - inner wing up IWH - inner wing heavy
TED - trailing edge down A - against D - inner wing down OWH - outer wing heavy

Spin block no.	Spin block	Stores: Loading	Stores: Description	Stores: Mass asymmetry, ft-lb	Spin characteristics: α, deg	Spin characteristics: ϕ, deg	Spin characteristics: V, ft/sec	Spin characteristics: Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
AMRAAM missiles													
70		2	Four AMRAAM's	0	[a]87-83	0 3U	240-260	190-145 (1.9-2.5)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{2}$, $2\frac{3}{4}$, $4\frac{1}{2}$, $3\frac{1}{2}$
85		2a	One AMRAAM on pylon	3010 IWH	80	1D	250	100-95 (3.6-3.8)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$\frac{3}{4}$
82		2a	One AMRAAM on pylon	3010 OWH	[a]87-86	0 1U	235-245	210-180 (1.7-2.0)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	3, 3, 5, $4\frac{3}{4}$
79		2b	One AMRAAM on wing tip	4860 IWH	[a]85-84	3D 1U	240-245	180-145 (2.0-2.5)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$1\frac{1}{2}$, $1\frac{3}{4}$
75		2b	One AMRAAM on wing tip	4860 OWH	[a]87-86	0 1D	235-245	180-165 (2.0-2.2)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	3, $3\frac{1}{4}$
88		2c	Two AMRAAM's (one on pylon; one on wing tip)	7830 OWH	[a]88-86	0 2U	240-245	200-190 (1.8-1.9)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$5\frac{3}{4}$, $5\frac{1}{4}$, 7, 6
Pylon-mounted AGM-65 missiles													
11		3	Six AGM-65's	0	86	1D	240	165 (2.2)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, $3\frac{1}{4}$
95		3a	Five AGM-65's	4860 OWH	[a]87-85	1U	240	210-200 (1.7-1.8)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	7, $6\frac{1}{2}$
97		3b	One AGM-65	4860 OWH	87	0	240	240-210 (1.5-1.7)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$6\frac{1}{2}$, $6\frac{3}{4}$

See footnotes in table IV.

TABLE VIII.- Concluded

TEU - trailing edge up W - with U - inner wing up IWH - inner wing heavy
TED - trailing edge down A - against D - inner wing down OWH - outer wing heavy

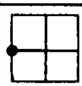
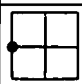
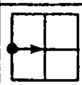
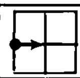
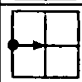
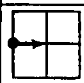
Spin block no.	Spin block	Stores: Loading	Stores: Description	Stores: Mass asymmetry, ft-lb	Spin characteristics: α, deg	Spin characteristics: φ, deg	Spin characteristics: V, ft/sec	Spin characteristics: Ω, deg/sec (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
SUU-65 stores													
105		5	Ten SUU-65's	0	88	7U 10D	290	225 (1.6)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	5, $4\frac{3}{4}$, 5
106		5a	Nine SUU-65's	7 860 OWH	87	7U 7D	285	260-210 (1.4-1.7)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	8, 7
TER-mounted AGM-65 missiles													
102		4	Six AGM-65's	0	86	1U	240	180 (2.0)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, $3\frac{1}{2}$
92		4a	Three AGM-65's	9 150 IWH	76	3U 13D	255	105 (3.4)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	1, $\frac{1}{4}$
109		4a	Three AGM-65's	9 150 IWH	87	1D	240	200 (1.8)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$5\frac{1}{2}$, 5, $5\frac{1}{2}$
370-gallon tanks													
121		8	Two 370-gallon tanks	0	[a]86-84	1U	250	180-165 (2.0-2.2)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{1}{4}$, 3
127		8a	One 370-gallon tank	18 300 IWH	87	0	245	180 (2.0)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	$2\frac{3}{4}$, $2\frac{3}{4}$
107		8a	One 370-gallon tank	18 300 OWH	89	1U 10D	250	260 (1.4)	30W / 30A	30TED / 0	25A / 25W	0 / 30W	>1, $12\frac{1}{2}$, 10
108		8a	One 370-gallon tank	18 300 OWH	79	10U 1D	265	120 (3.0)	30W / 30A	30TED / 0	25W / 25W	0 / 30W	3, 5

See footnotes in table IV.

TABLE IX.- EFFECT OF 5000-ft-lb MASS ASYMMETRY ON INVERTED SPIN AND RECOVERY CHARACTERISTICS

[Leading-edge flaps 0°]

TEU - trailing edge up
TED - trailing edge down
W - with
A - against
U - inner wing up
D - inner wing down
IWH - inner wing heavy
OWH - outer wing heavy

Spin block no.	Spin block	Lateral mass asymmetry	Spin characteristics				Control deflection, deg (For spin / For recovery)				Turns for recovery
			α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	δ_r	δ_e	δ_a	δ_{de}	
148		OWH	No spin				15W	0	25A	0	
e152		OWH	No spin				30W	0	25A	0	
e152		OWH	-80 -65	25U 6D	289	95 (3.8)	30W / 0	0 / 0	25A / 0	0 / 0	1
149		IWH	-66	10U	296	70 (5.3)	15W / 0	0 / 0	25A / 0	0 / 0	∞
150		IWH	-73 -52	2U 11D	289	65 (5.6)	30W / 0	0 / 0	25A / 0	0 / 0	$>3\frac{1}{2}$, ∞
151		IWH	-73 -52	2U 11D	289	65 (5.6)	30W / 30A	0 / 0	25A / 0	0 / 0	$\frac{1}{4}$, $\frac{1}{2}$

See footnotes in table IV.

TABLE X.- SPIN-RECOVERY PARACHUTE TESTS FOR ERECT SPINS

[Leading-edge flaps 36.5° down; C_D = 0.50]

TEU - trailing edge up   W - with   U - inner wing up
TED - trailing edge down   A - against   D - inner wing down

Spin block no.	Spin block	Parachute		Spin characteristics				Control deflection, deg (For spin / For recovery)				Turns for recovery
		Diameter, ft	Towline length, d, ft	α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	δ_r	δ_e	δ_a	δ_{de}	
294		28.2	75	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$3\frac{1}{4}$, $3\frac{1}{2}$, 4, $3\frac{1}{4}$, $4\frac{3}{4}$, $3\frac{1}{2}$, 3
296		28.2	100	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$3\frac{1}{4}$, $2\frac{1}{2}$, 2, $3\frac{3}{4}$, $3\frac{1}{2}$
298		28.2	125	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	5, $8\frac{1}{2}$
297		28.2	150	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$8\frac{3}{4}$, $9\frac{1}{2}$
248		31.5	100	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$1\frac{1}{4}$, $1\frac{3}{4}$, $1\frac{1}{4}$
271		34.2	100	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$2\frac{1}{2}$, $2\frac{1}{4}$, $2\frac{3}{4}$
274		34.2	150	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	$4\frac{1}{2}$, 8
268		39.1	100	[a]86-83	1U	245-260	165-130 (2.2-2.0)	30W	30TED	25A	0	[h]$2\frac{1}{2}$, [h]$1\frac{1}{2}$

See footnotes in table IV.

TABLE XI.- COMPARISON OF PARACHUTE SIZES FOR RECOVERIES WITH ASYMMETRIC LOADINGS

[Leading-edge flaps 36.5° down; C_D = 0.50; Towline length = 100 ft]

TEU - trailing edge up   W - with   U - inner wing up
TED - trailing edge down   A - against   D - inner wing down

Spin block no.	Spin block	Lateral mass asymmetry, ft-lb (outer wing heavy)	Spin characteristics: α, deg	φ, deg	V, ft/sec	Ω, (sec/turn)	Control deflection, deg (For spin / For recovery): δ_r	δ_e	δ_a	δ_{de}	Turns for recovery
39.1-ft-diameter parachute											
268		0	[a]86-83	1U	245-260	165-130 (2.2-2.7)	30W	30TED	25A	0	$h_{2\frac{1}{2}}$, $h_{1\frac{1}{2}}$
269		5 000	86	14U 6D	260	200 (1.8)	30W	30TED	25A	0	$h_{3\frac{1}{2}}$, $h_{4\frac{1}{4}}$, h_8
270		10 000	93 82	17U 7D	260	225 (1.6)	30W	30TED	25A	0	h_{10}, h,t_3, $h,t_{4\frac{1}{2}}$, h_{10}
262		15 000	87	12U 1D	260	240 (1.5)	30W	30TED	25A	0	$h_{>10}$, h,t_4, $t_{4\frac{1}{4}}$, h_8, t_3, h_{10}
34.2-ft-diameter parachute											
271		0	[a]86-83	1U	245-260	165-130 (2.2-2.7)	30W	30TED	25A	0	$2\frac{1}{2}$, $2\frac{1}{4}$, $2\frac{3}{4}$
256		5 000	86	14U 6D	260	200 (1.8)	30W	30TED	25A	0	h_5, $h_{4\frac{3}{4}}$, $h_{4\frac{1}{2}}$
253		10 000	93 82	17U 7D	260	225 (1.6)	30W	30TED	25A	0	h,t_4, $h,t_{3\frac{1}{4}}$, h_5, $h_{7\frac{1}{2}}$, $h_{4\frac{1}{2}}$, h_5, h_6
261		15 000	87	12U 1D	260	240 (1.5)	30W	30TED	25A	0	$h_{>10}$, h_{∞}, h,t_6, h_{13}
252		20 000	88	10U 2U	260	255 (1.4)	30W	30TED	25A	0	h,t_6, $h,t_{7\frac{1}{2}}$, h_{12}, h,t_9, h_{15}

See footnotes in table IV.

TABLE XI.- Concluded

TEU - trailing edge up W - with U - inner wing up
TED - trailing edge down A - against D - inner wing down

Spin block no.	Spin block	Lateral mass asymmetry, ft-lb (outer wing heavy)	Spin characteristics				Control deflection, deg (For spin / For recovery)				Turns for recovery
			α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	δ_r	δ_e	δ_a	δ_{de}	
28.2-ft-diameter parachute											
250		0	[a]86-83	1U	245-260	165-130 (2.2-2.7)	30W	30TED	25A	0	$2\frac{1}{4}$, $2\frac{1}{2}$, 2, $3\frac{3}{4}$, $3\frac{1}{2}$
276		5 000	86	14U 6D	260	200 (1.8)	30W	30TED	25A	0	$5\frac{3}{4}$, $4\frac{1}{2}$, [h]5, $3\frac{3}{4}$, $7\frac{1}{4}$
277		10 000	93 82	17U 7D	260	225 (1.6)	30W	30TED	25A	0	[h]>8, $12\frac{1}{2}$
278		15 000	87	12U 1D	260	240 (1.5)	30W	30TED	25A	0	$7\frac{1}{4}$, [h]11, $20\frac{1}{2}$
251		20 000	88	10U 2U	260	255 (1.4)	30W	30TED	25A	0	[h]13, [h]10, [h,t]$6\frac{1}{2}$, [h]>13

See footnotes in table IV.

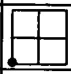
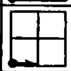
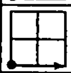
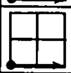
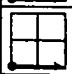
TABLE XII.- EFFECT OF CONTROL MOVEMENT ON PARACHUTE PERFORMANCE WITH ASYMMETRIC LOADINGS

[Leading-edge flaps 36.5° down; C_D = 0.50; Parachute diameter = 34.2 ft; Towline length = 100 ft]

TEU - trailing edge up
TED - Trailing edge down

W - with
A - against

U - inner wing up
D - inner wing down

Spin block no.	Spin block	Lateral mass asymmetry, ft-lb (outer wing heavy)	Spin characteristics				Control deflection, deg (For spin / For recovery)				Turns for recovery
			α, deg	ϕ, deg	V, ft/sec	Ω, deg/sec (sec/turn)	δ_r	δ_e	δ_a	δ_{de}	
256		5 000	86	14U 6D	260	200 (1.8)	30W	30TED	25A	0	$^{h}5$, $^{h}4\frac{3}{4}$, $^{h}4\frac{1}{2}$
257		5 000	86	14U 6D	260	200 (1.8)	30W / 0	30TED / 30TED	25A / 0	0 / 0	$^{h}3\frac{1}{2}$, $^{h}3\frac{1}{2}$, $^{h}5$
258		5 000	86	14U 6D	260	200 (1.8)	30W / 30A	30TED / 30TED	25A / 25W	0 / 0	$^{h}3\frac{1}{4}$, $^{h}3\frac{1}{2}$, $^{h}3$, $^{h}3\frac{1}{2}$
259		10 000	93 82	17U 7D	260	225 (1.6)	30W / 30A	30TED / 30TED	25A / 25W	0 / 0	$^{h}3\frac{1}{2}$, $^{h}3\frac{1}{2}$, $^{h}4\frac{1}{2}$, $^{h}3$, $^{h}4$, $^{h}3\frac{1}{2}$, $2\frac{1}{2}$
260		15 000	87	12U 1D	260	240 (1.5)	30W / 30A	30TED / 30TED	25A / 25W	0 / 0	$^{h}6$, $^{h}4\frac{1}{2}$

See footnotes in table IV.

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL LOADING 1

[Developed spin data presented for rudder-full-with spins; recovery attempted by full rudder reversal and roll controls as noted]

Leading-edge flaps	Center of gravity	Altitude	IYMP
36.5° down	0.460$\bar{c}$	25 000 ft	-741×10^{-4}

U-inner wing up

D-inner wing down

Roll control against ← → Roll control with

↑ Elevons T.E. up (as in stick aft)

↓ Elevons T.E. down (as in stick forward)

Spin block 1 (a)

87-83	1U
250-270	190-100 (1.9-3.7)

1 — m: 3, b2, $4\frac{3}{4}$, $5\frac{3}{4}$, 3, $3\frac{1}{2}$

10 — b$2\frac{1}{4}$, $2\frac{3}{4}$, $4\frac{1}{2}$, b2, b$2\frac{1}{4}$

11 — 3, $2\frac{1}{4}$, $3\frac{1}{4}$, b$1\frac{3}{4}$, $4\frac{1}{2}$

13 — o: 9

12 — ∞, $8\frac{1}{2}$

Spin block 4 (f): No spin (m)

ℓ

	k		k	
α, φ	80 / 72	3U / 9D	80 / 70	6U / 9D
V, Ω	260	85 (4.3)	300	55 (6.7)
Turns for recovery	$2\frac{1}{4}$, $1\frac{1}{2}$		$\frac{1}{8}$, $\frac{1}{8}$	

27 — $\frac{1}{8}$, $\frac{1}{8}$

28 — $\frac{1}{8}$, $\frac{1}{8}$

29 — ∞

Spin block 7 (f): No spin

Spin block 2 (a)

87-83	2U / 1D
240-270	200-110 (1.8-3.3)

2 — m: 5, $4\frac{1}{2}$, $7\frac{3}{4}$, 4, $6\frac{1}{2}$, b$1\frac{3}{4}$, b$2\frac{1}{2}$, 3,4,5,6

14 — i: $4\frac{1}{2}$, $4\frac{1}{2}$, $3\frac{1}{2}$

15 — $4\frac{3}{4}$, $5\frac{3}{4}$, $4\frac{3}{4}$, 3, $5\frac{1}{2}$, b$2\frac{1}{2}$, $5\frac{1}{2}$

17 — o: 6, 8, ∞, ∞

19 — $8\frac{1}{2}$, $9\frac{1}{2}$, $11\frac{1}{2}$

Spin block 5 (f): No spin (m)

ℓ

	k		k	
α, φ	85 / 72	4U / 3D	72 / 64	6U / 8D
V, Ω	250	120 (3.0)	280	45 (8.0)
Turns for recovery	2, $2\frac{3}{4}$		$\frac{1}{8}$, $\frac{1}{4}$	

25 — $\frac{1}{8}$, $\frac{1}{8}$

Spin block 8 (f, j): No spin

Spin block 3 (a)

86-83	2U / 2D
245-265	165-130 (2.2-2.7)

3 — m: b$2\frac{1}{2}$, $3\frac{3}{4}$, $3\frac{1}{2}$, $3\frac{3}{4}$, $4\frac{1}{2}$, 5, 6, $3\frac{1}{4}$, $4\frac{1}{2}$

21 — 3, $4\frac{1}{2}$, b$2\frac{1}{4}$, $2\frac{3}{4}$, 6, $5\frac{3}{4}$

22 — i: 4, $3\frac{1}{4}$, 4, $2\frac{3}{4}$, 2, 3, b$1\frac{1}{2}$, b$1\frac{3}{4}$

23 — 7, $10\frac{3}{4}$, 10, 11, 8, ∞

26 — ∞, ∞

Spin block 6 (f): No spin (m)

ℓ

	k		k	
α, φ	89 / 80	10U / 7D	69 / 63	4U / 5D
V, Ω	250	125 (2.9)	285	50 (7.1)
Turns for recovery	$2\frac{1}{4}$, $1\frac{1}{4}$		$\frac{1}{4}$	
α, φ	78	4U / 7D		
V, Ω	255	120 (3.0)		

16 — u: $\frac{1}{8}$

Spin block 9 (f): No spin

Key

Spin block number

α, deg	φ, deg
V, ft/sec	Ω, deg/sec (sec/turn)
Turns for recovery	

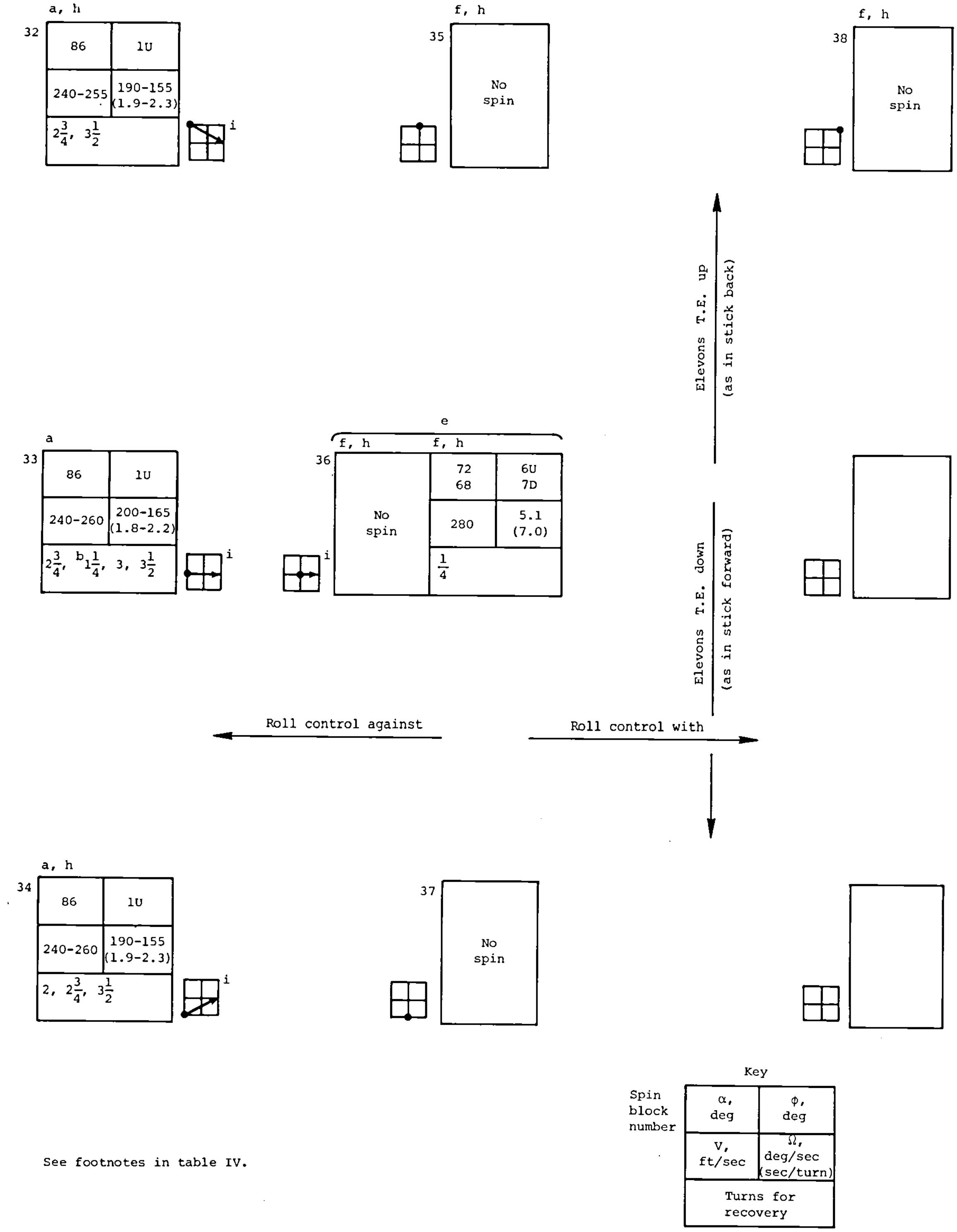
See footnotes in table IV.

CHART 2.- SPIN AND RECOVERY CHARACTERISTICS FOR FORWARD CENTER OF GRAVITY

[Developed spin data presented for rudder-full-with spins; recovery attempted by full rudder reversal and roll controls as noted]

Model loading	Leading-edge flaps	Center of gravity	Altitude	IYMP
6	36.5° down	$0.430\bar{c}$	25 000 ft	-719×10^{-4}

U-inner wing up D-inner wing down



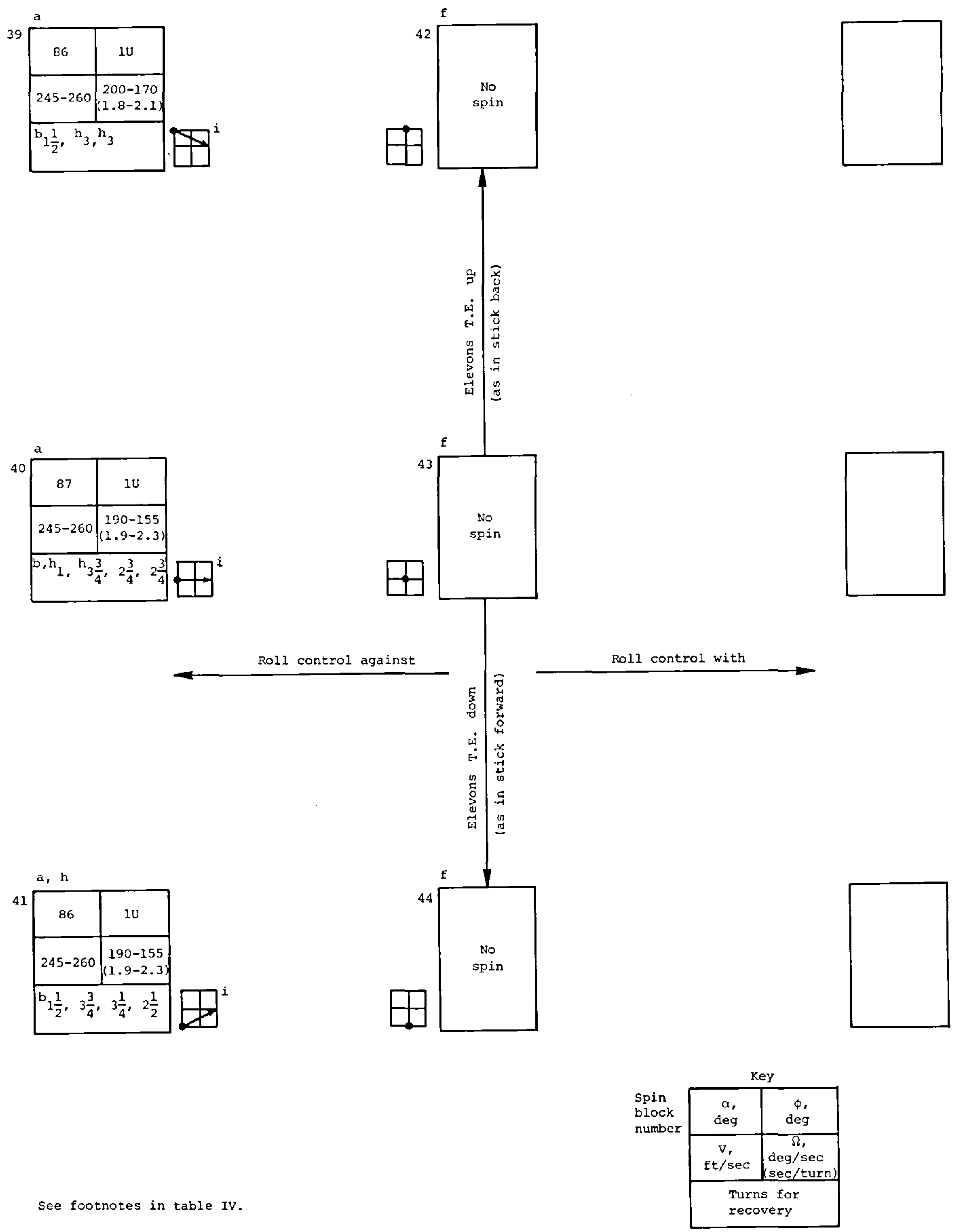
See footnotes in table IV.

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS FOR AFT CENTER OF GRAVITY

[Developed spin data presented for rudder-full-with spins; recovery attempted by full rudder reversal and roll controls as noted]

Model loading	Leading-edge flaps	Center of gravity	Altitude	IYMP
7	36.5° down	0.491$\bar{c}$	25 000 ft	-713×10^{-4}

U-inner wing up



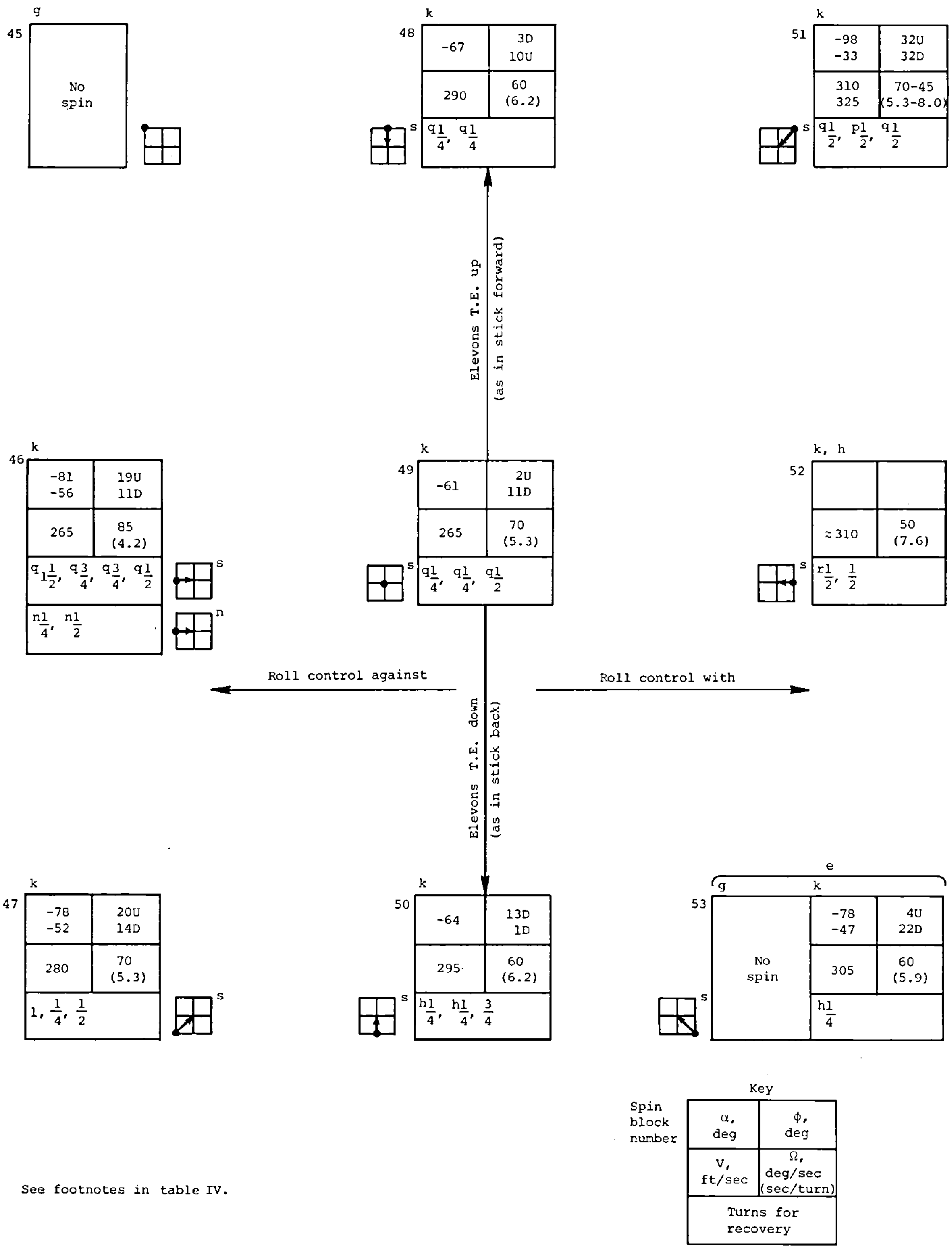
See footnotes in table IV.

CHART 4.- INVERTED SPIN AND RECOVERY CHARACTERISTICS

[Developed spin data presented for rudder-full-with spins; recovery attempted by movement of all controls to neutral unless otherwise noted]

Model loading	Leading-edge flaps	Center of gravity	Altitude	IYMP
1	0°	$0.460\bar{c}$	25 000 ft	-741×10^{-4}

U-inner wing up   D-inner wing down



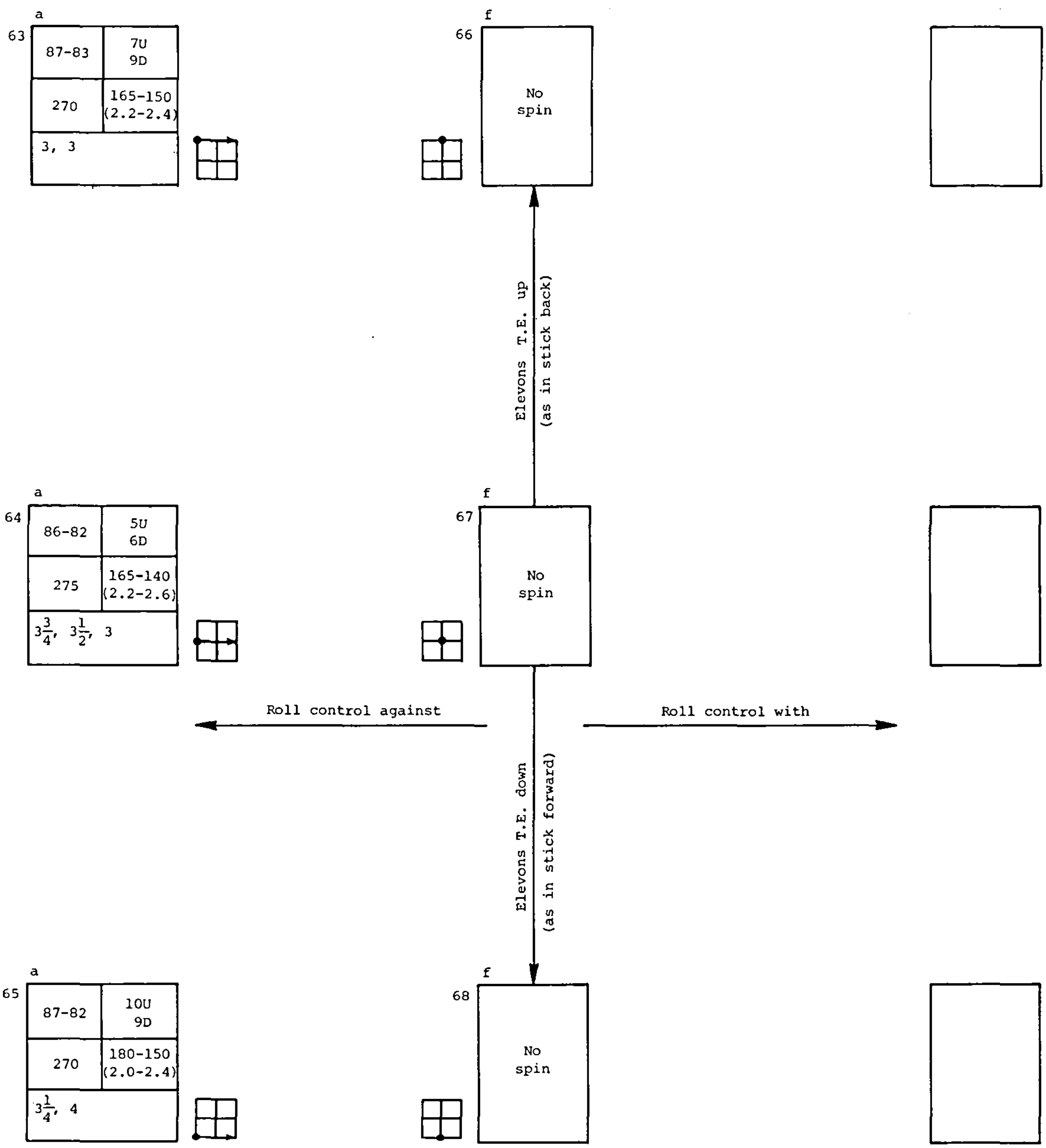
See footnotes in table IV.

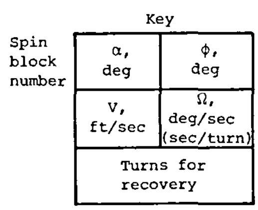
CHART 5.- SPIN AND RECOVERY CHARACTERISTICS FOR ALL-MOVING VERTICAL TAIL AND ALL-MOVING WING TIPS

[Developed spin data presented for vertical-tail-full-with spins; recovery attempted by full vertical-tail and wing-tips reversal]

Center of gravity	Altitude	IYMP
$0.460\bar{c}$	25 000 ft	-741×10^{-4}

U-inner wing up D-inner wing down





See footnotes in table IV.

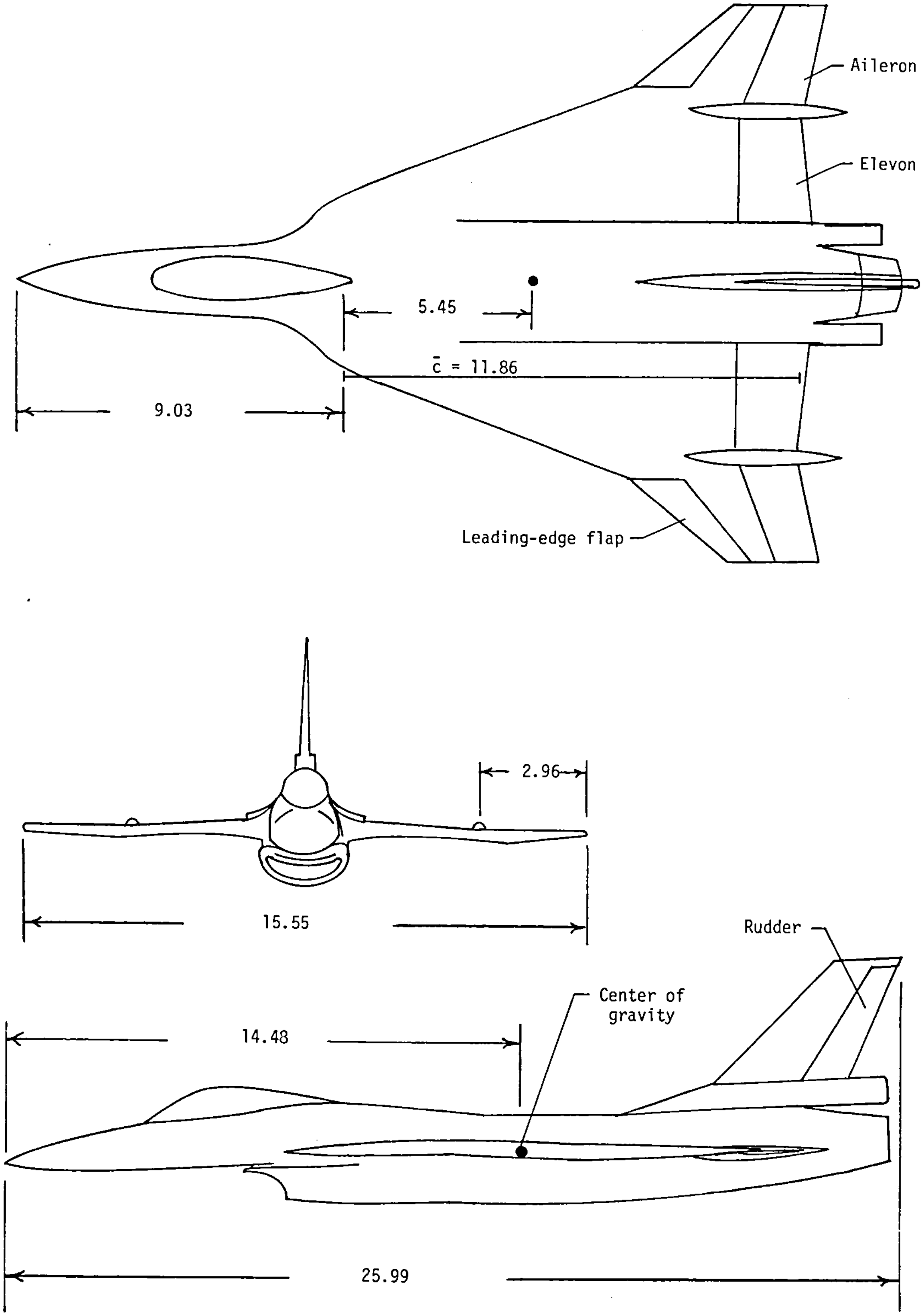
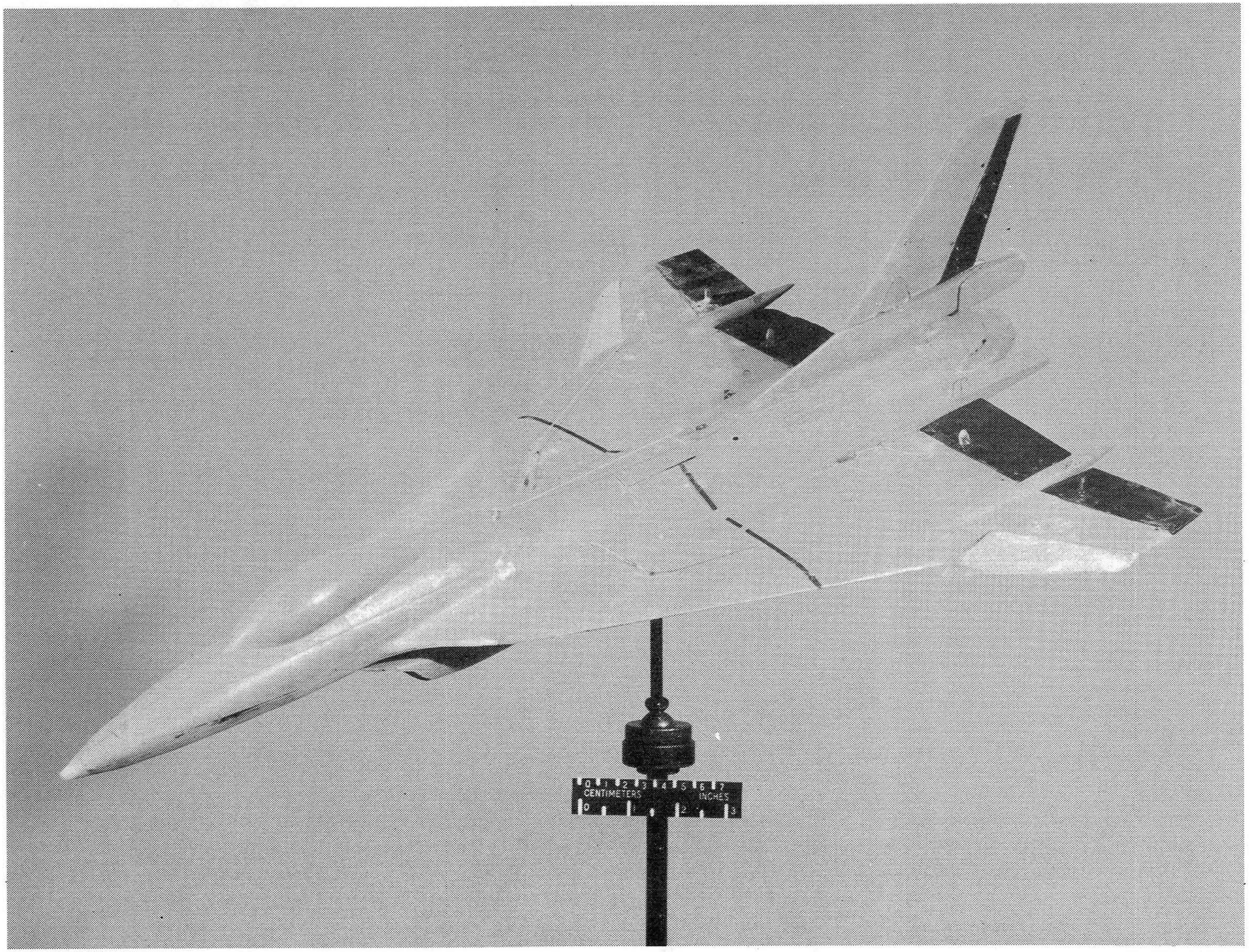


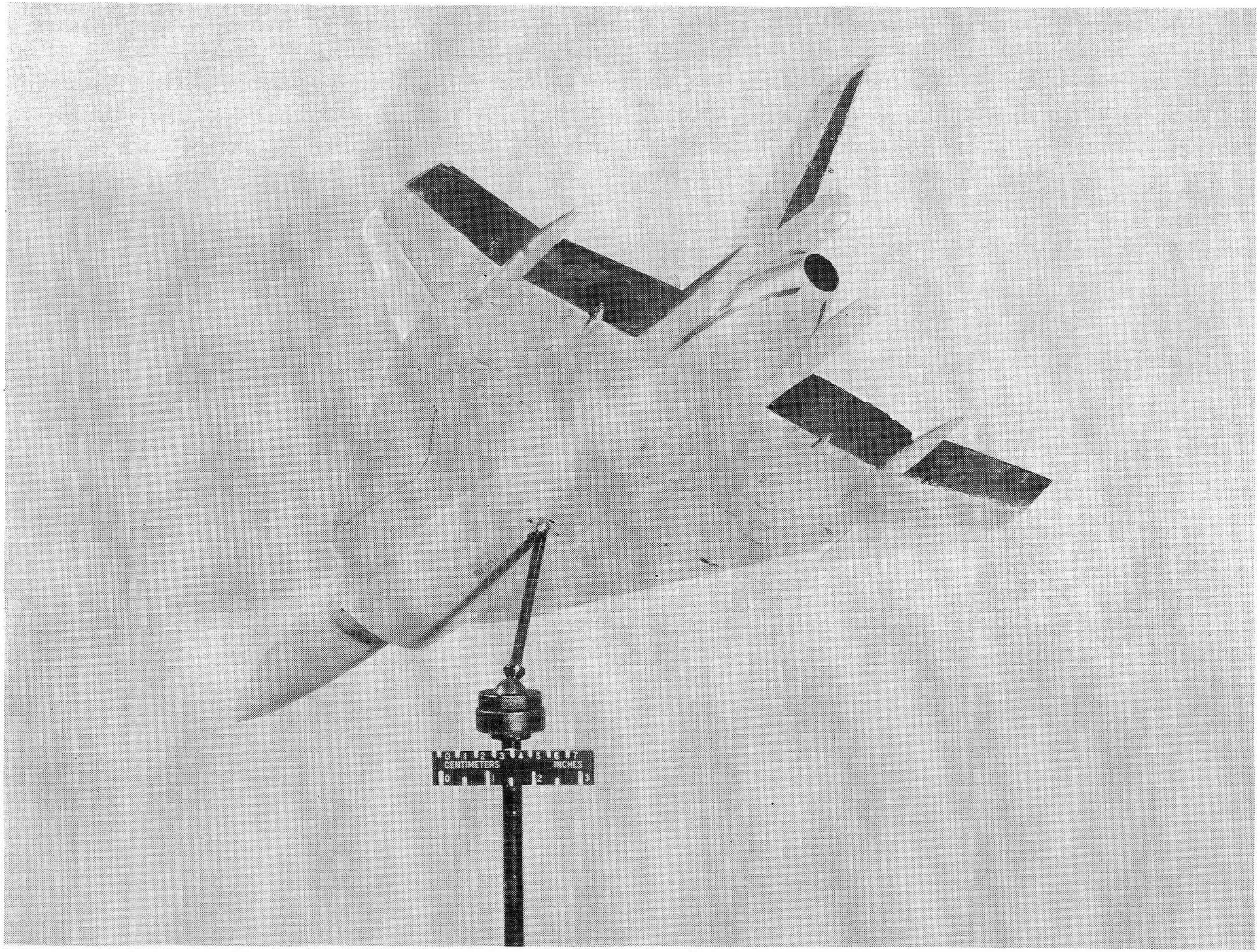
Figure 1.- Three-view drawing of the 1/25-scale model of the F-16XL airplane. Center-of-gravity position shown is $0.460\bar{c}$. Dimensions are in inches.



L-82-5073

(a) View from above.

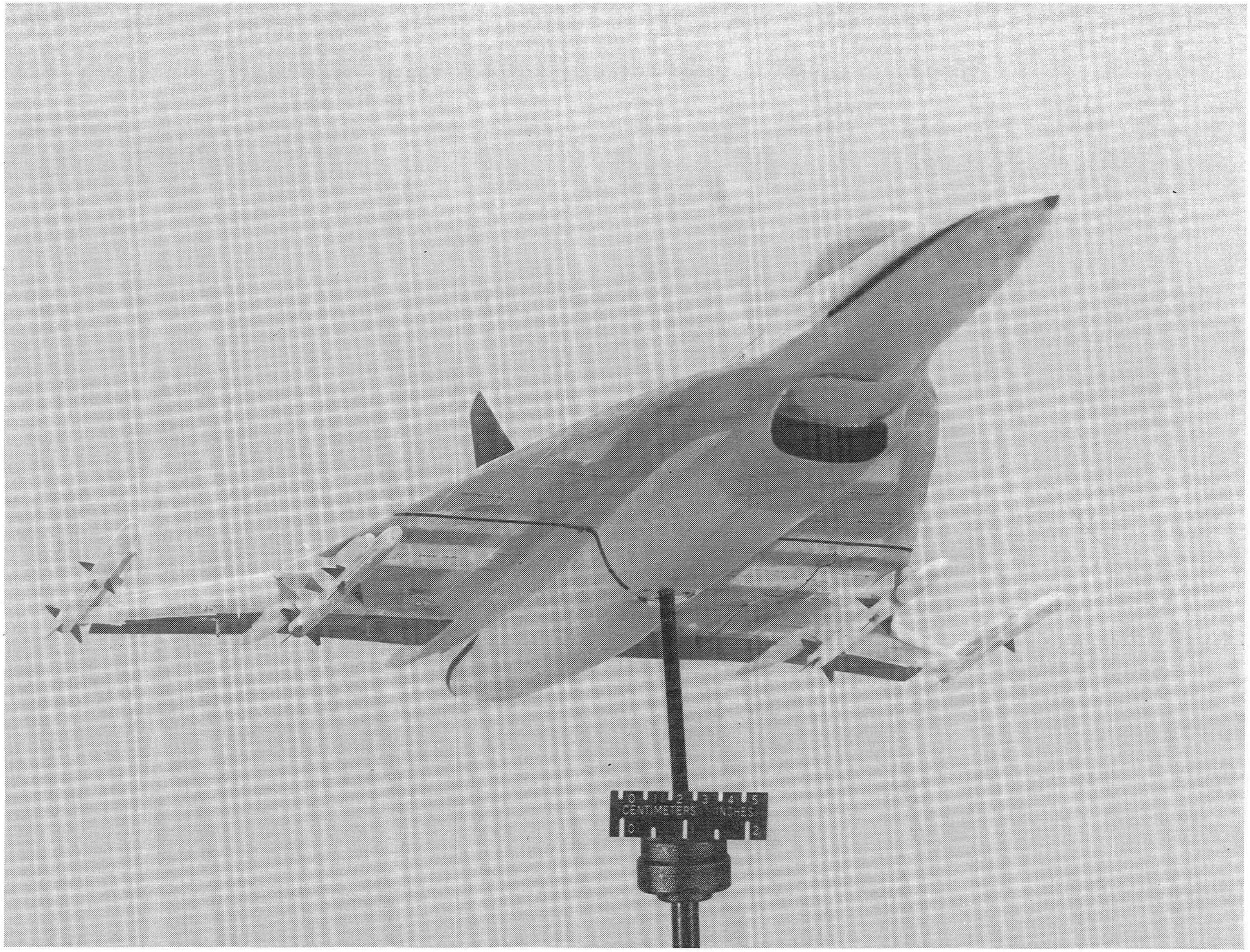
Figure 2.- Model loading 1 (no external stores).



L-82-5074

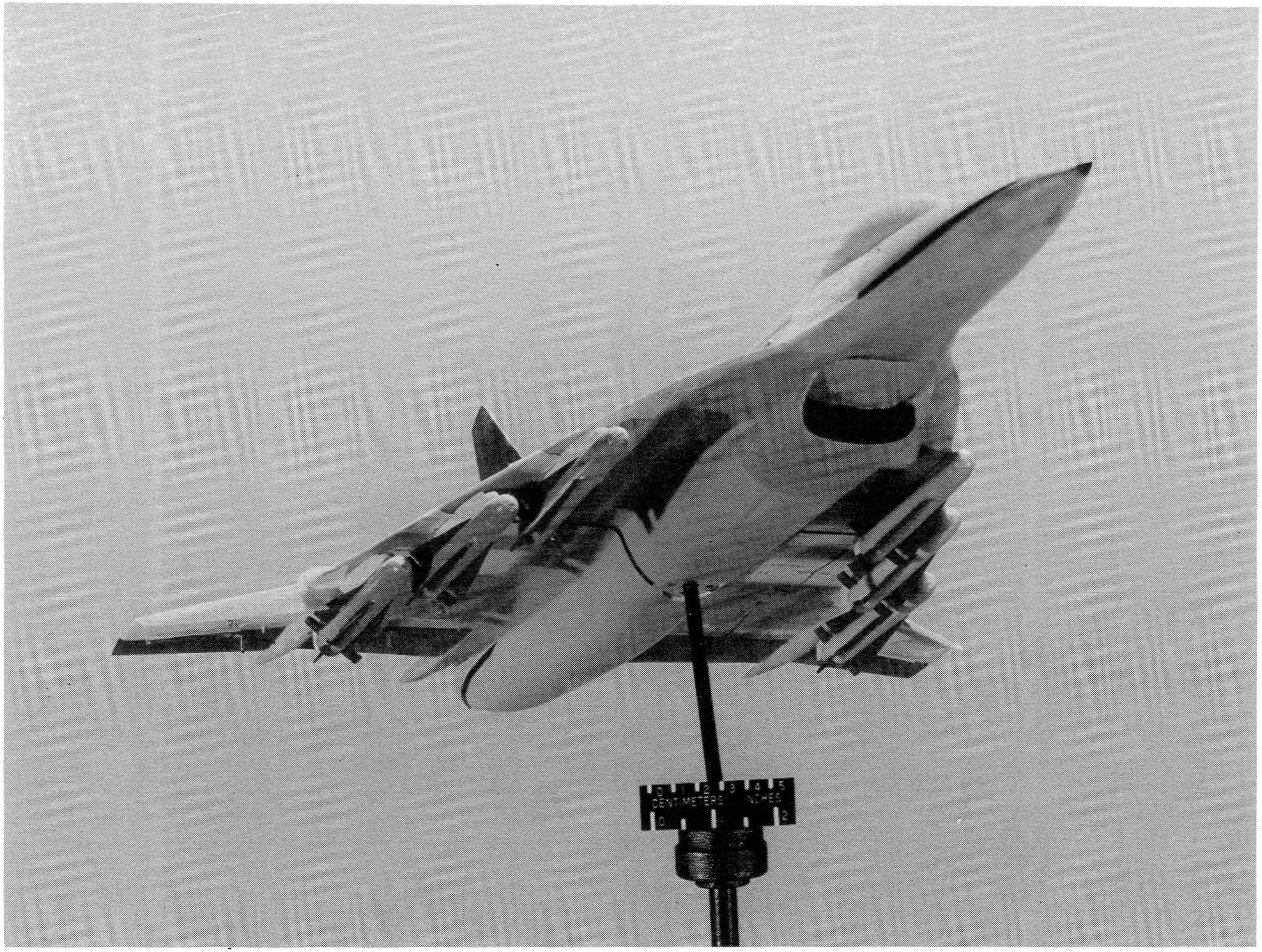
(b) Rear view from below.

Figure 2.- Concluded.



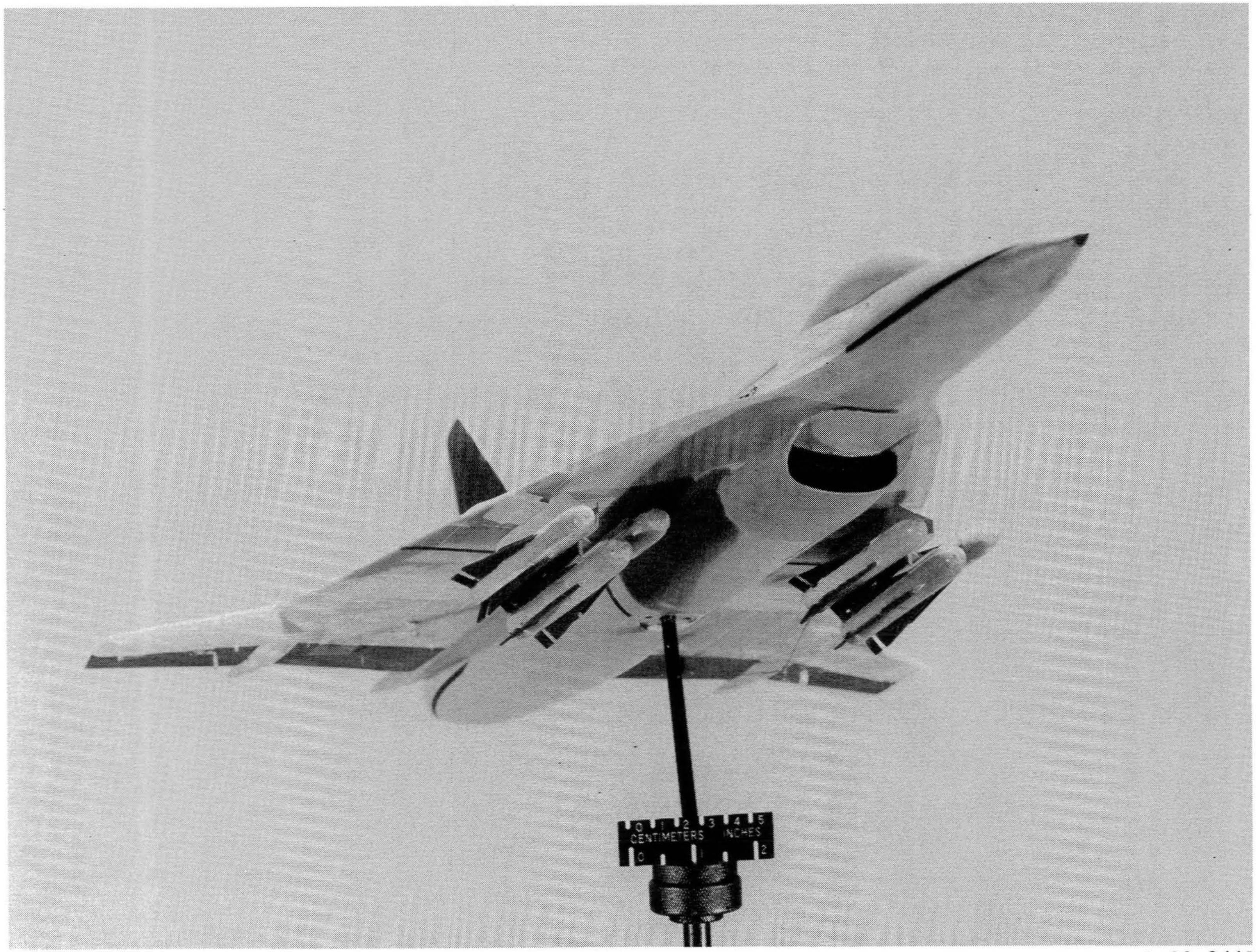
L-80-9121

Figure 3.- Model loading 2 (AMRAAM missiles).



L-80-9125

Figure 4.- Model loading 3 (pylon-mounted AGM-65 missiles).

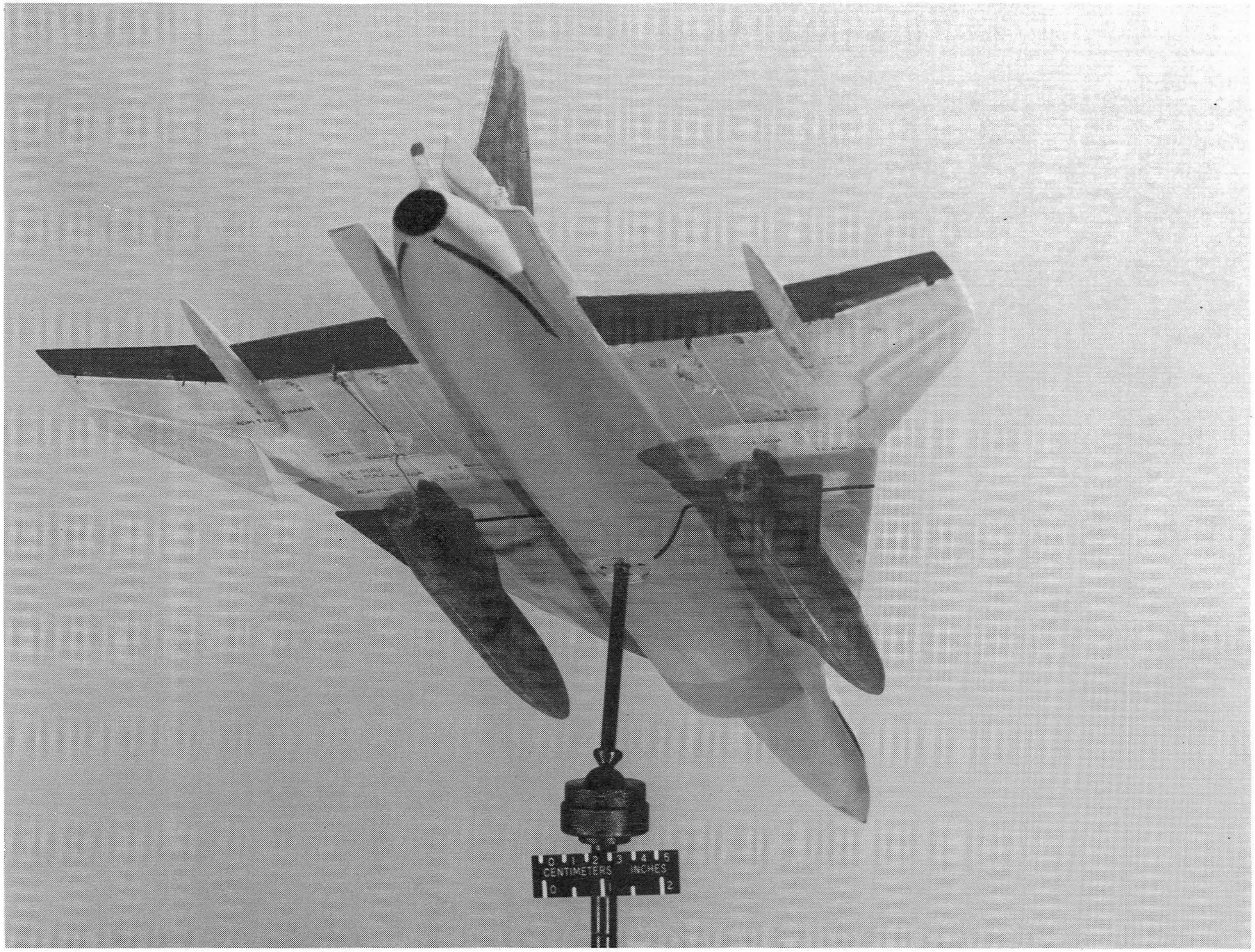


L-80-9118

Figure 5.- Model loading 4 (TER-mounted AGM-65 missiles).

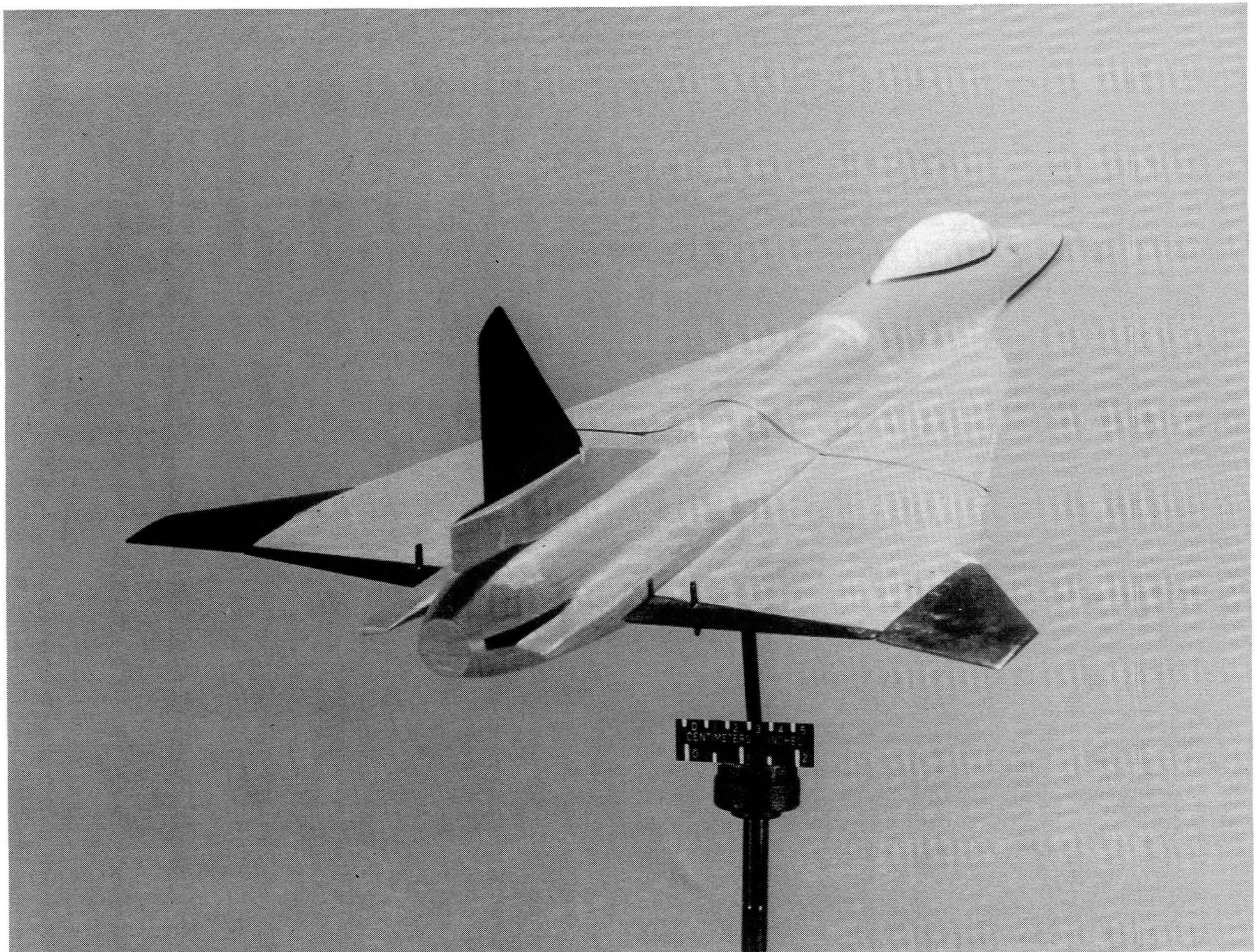
L-80-9122

Figure 6.- Model loading 5 (SUU-65 stores).



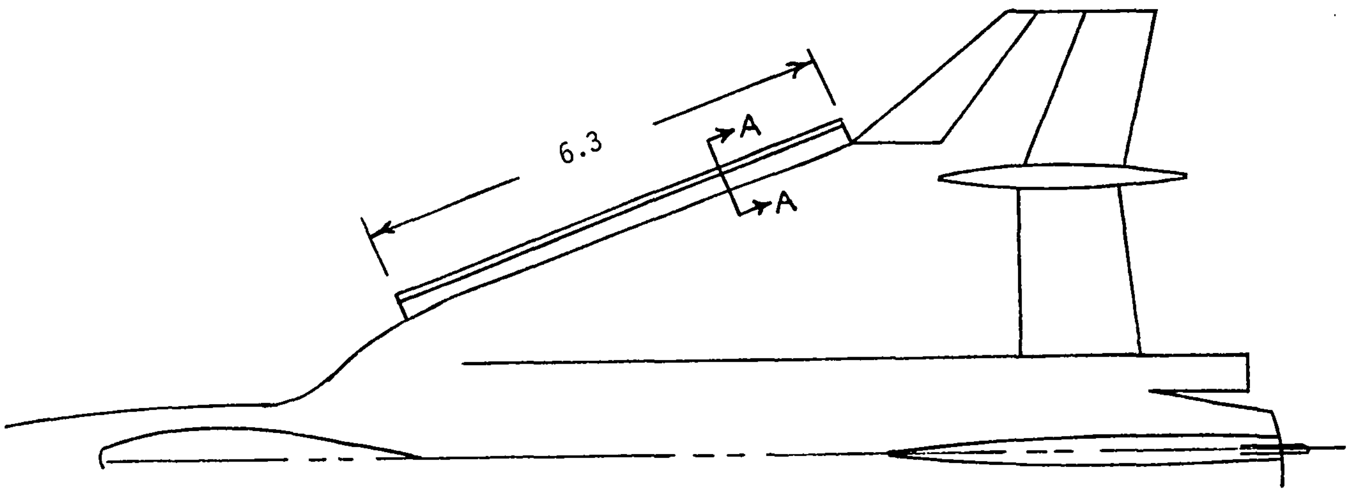
L-80-9126

Figure 7.- Model loading 8 (370-gallon tanks).



L-80-9109

Figure 8.- Model with all-moving vertical tail and all-moving wing tips.



Section A-A

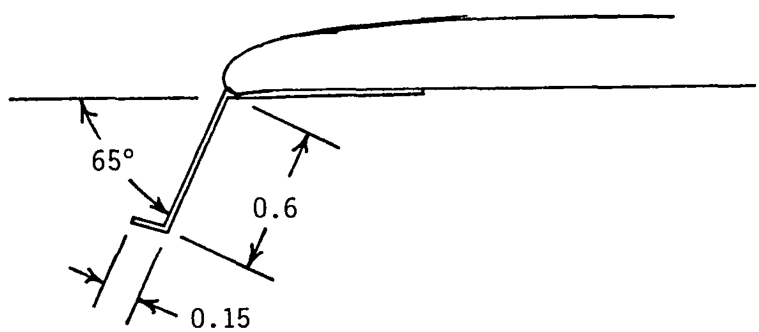
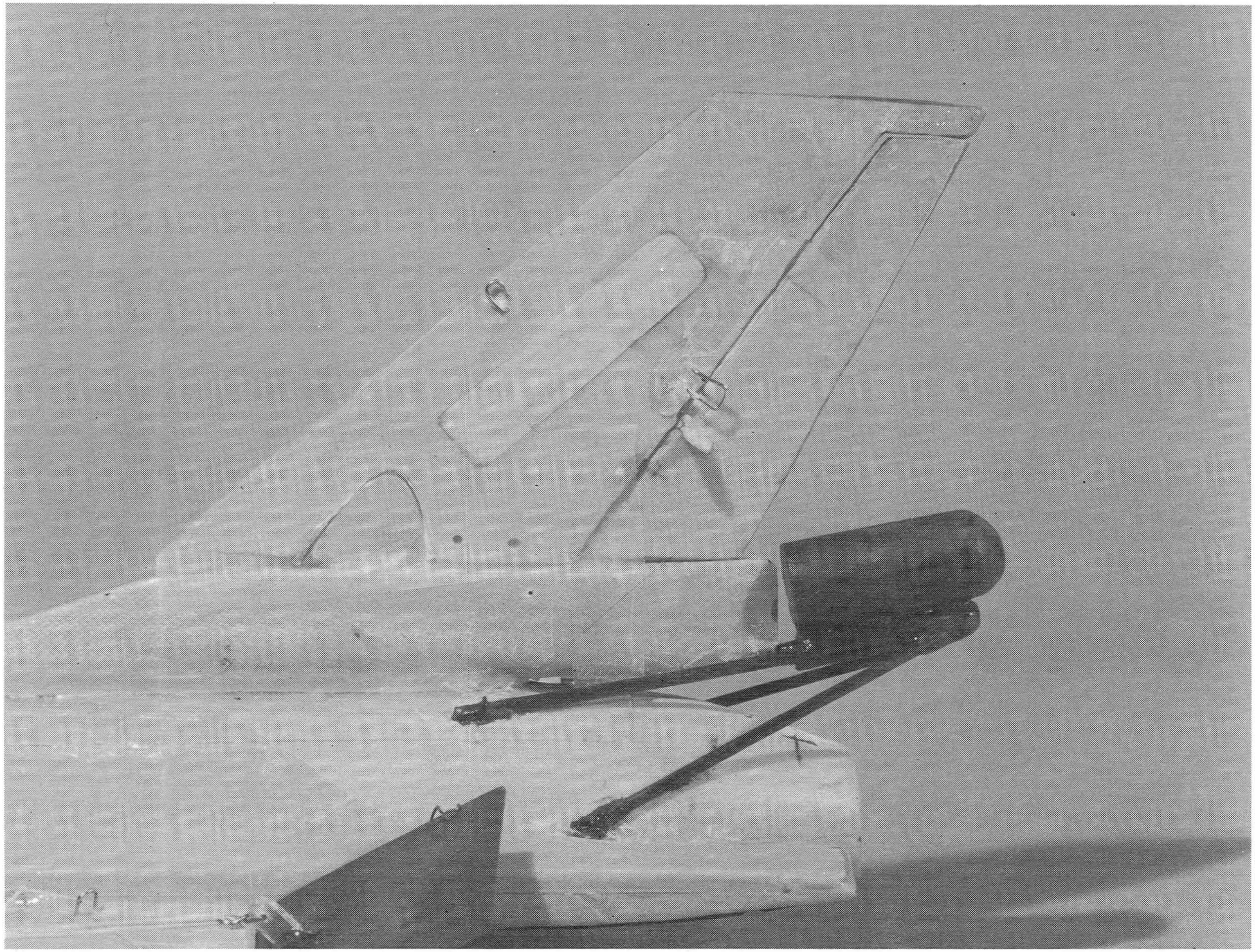


Figure 9.- Drawing of a vortex flap tested on the model. Dimensions are in inches.



L-82-4259

Figure 10.- Scaled spin chute canister and support structure installed on the model.

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16. Abstract

A spin-tunnel investigation of the spin and recovery characteristics of a 1/25-scale model of the General Dynamics F-16XL airplane has been conducted in the Langley Spin Tunnel. Tests included erect and inverted spins at various symmetric and asymmetric loading conditions. The required size of an emergency spin-recovery parachute was determined.

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